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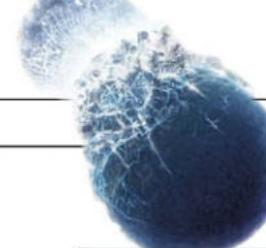
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A collision of two neutron stars
spat out approximately 200
Earth-masses of pure gold → p17

WELCOME



In 2000, Bill Clinton and Tony Blair took to the international stage to announce the completion of the most "wondrous map ever produced by humankind", after an international team of scientists had completed the first draft of the human genome. The message was clear: we had learned to read our own 'instruction book', encoded within our DNA, and this would deliver us into a new era of humanity. Clinton and Blair said that a

medical revolution was around the corner – one that would surpass the discovery of antibiotics. "In coming years doctors increasingly will be able to cure diseases like Alzheimer's, Parkinson's, diabetes and cancer by attacking their genetic roots," said Clinton.

But a decade later, the world was still waiting for direct treatments based on this incredible piece of work. It seemed that diseases were far too complex, and decoding genomes was too expensive and slow. "Genomics is a way to do science, not medicine," said Harold Varmus, then director of the National Cancer Institute.

But it seems we're at a turning point. If we learned how to read our genome's instructions in 2000, then in this decade we've started uncovering how to write our own version. Now, 17 years after the first draft was completed, we're on the cusp of a medical revolution that could finally realise the potential of the Human Genome Project. Turn to p44 to discover how medicine is about to change forever.

Plus, this month marks our 25th birthday! Have you been reading since the first issue? If so, we'd love to hear from you – get in touch at reply@sciencefocus.com

Daniel Bennett, Editor

IN THIS ISSUE



JO CARLOWE

Our brains are flawed. If we accept that, then we can overcome our own defects. Jo reveals the promising research hoping to help correct our biases. → p63



TIMANDRA HARKNESS

BBC Focus has turned 25! We asked Timandra, of BBC Radio 4's *FutureProofing*, to look back at some of the predictions we've made over the last 25 years. → p54



PROF TIM SPECTOR

Tim spent three days living with the Hadza, a group of hunter-gatherers in Tanzania, to see if rewilding his diet would make him healthier. → p76

WHAT WE'VE FOUND OUT THIS MONTH

Drugs commonly given to treat depression, asthma and diabetes are ineffective in up to 40 per cent of people they are prescribed to → p44



After eating only McDonald's for 10 days straight, a person lost 40 per cent of their microbial gut diversity → p76



Adding some water to whisky makes it taste better → p96



When taught sign language, chimps begin to swear → p106

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The mpg figures quoted are sourced from official EU-regulated test results (EU Directive and Regulation 692/2008), are provided for comparability purposes and may not reflect your actual driving experience.



Go Further

CONTENTS



33

REGULARS

10 Eye opener

Stunning images from around the planet.

14 Reply

Your letters and emails.

17 Discoveries

All of this month's top science news.
PLUS: What is exploding head syndrome?

33 Innovations

The best tech news and coolest gadgets.
PLUS: Nuraphones on test.

75 Helen Czerski

Helen studies acoustics in the wind.

95 Q&A

Why does spicy food make my nose run?
Does chocolate give you spots? What
makes mozzarella cheese so stretchy?
These questions, and others, answered!

104 Out there

All the best science y activities.

112 Crossword

It's time to strain your brain.

114 My life scientific

We talk to materials scientist Prof Mark
Miodownik about getting stabbed,
being bald and investigating a can's
mysterious contents.

52 Subscribe

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book when you subscribe!

44

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54

FEATURES

A future without illness

44

Why personalised medicine is coming, and how it's going to help us beat disease.

Flying cars and robot butlers

54

To mark our 25th birthday, we take a look at some of the future tech that's closer than you think.

Us vs them: why your brain hates other people

63

It turns out that even the most liberal among us may have brains that harbour biases.

Is there life after Mars?

70

We catch up with Andy Weir, author of *The Martian*, to talk about his new book *Artemis*.

Rewild your diet

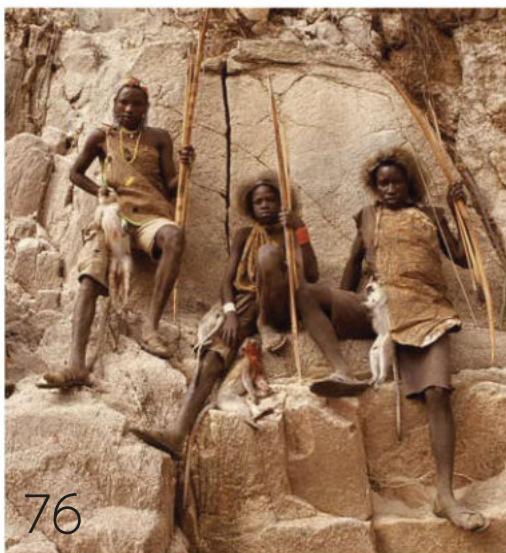
76

Find out how eating like a hunter-gatherer can supercharge your gut and make you healthier.

The nuclear pioneer who escaped the Nazis

83

The little known story of the Austrian physicist who launched the nuclear age.



70

76

MORE FOR YOU

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SPECIAL ISSUE



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Going for gold

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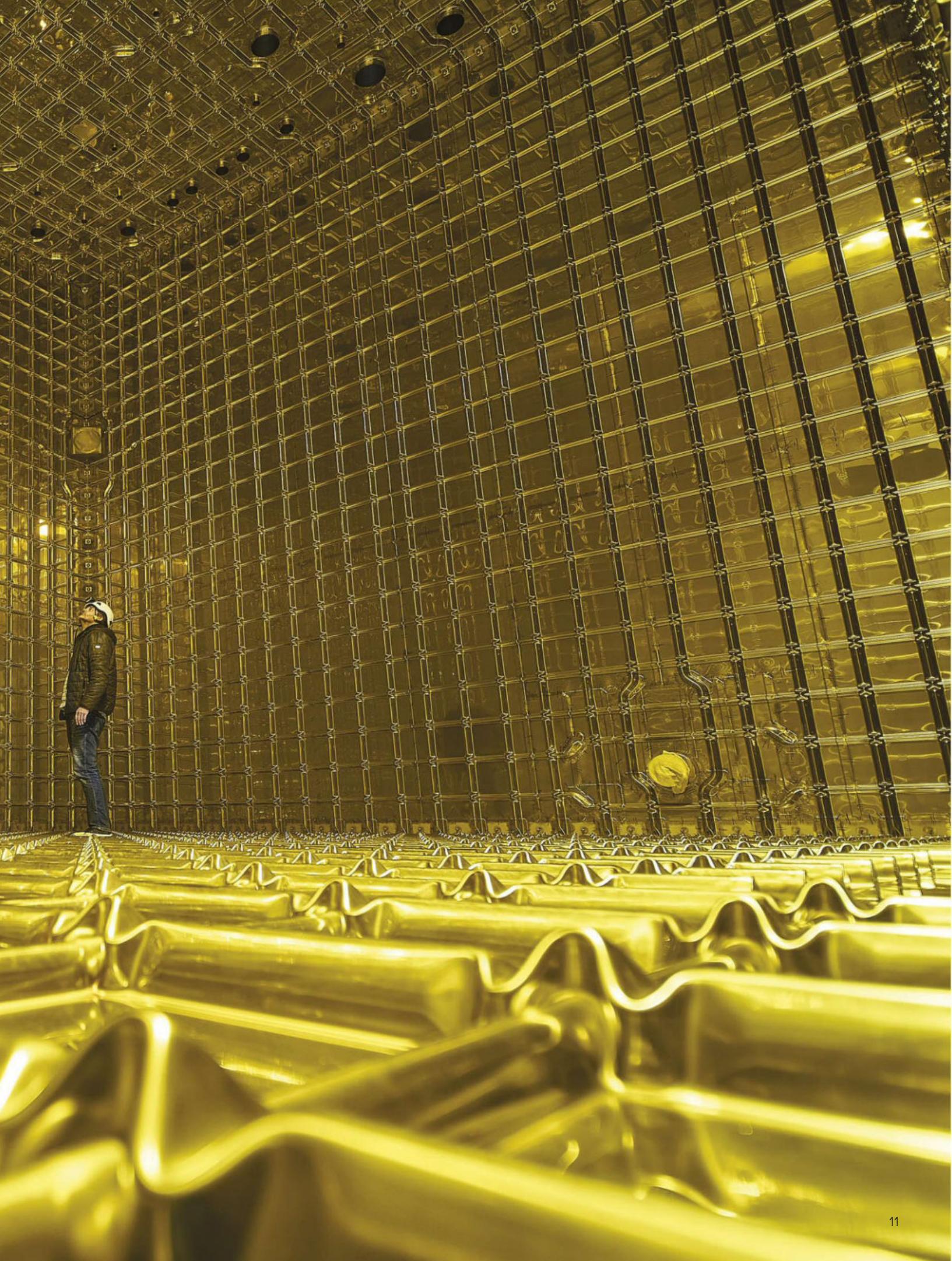
Neutrinos may be the shyest things in the Universe – trillions of the subatomic, near massless particles hurtle straight through the Earth every second but they barely react with anything. This makes it a problem for researchers wanting to study them. Enter this gleaming metallic lattice, which is a prototype neutrino detector currently under construction at CERN in Geneva, Switzerland.

Each detector measures 10 x 10 x 10m and will be filled with 800 tonnes of liquid argon, making them the largest of their type ever made. The idea is that neutrinos colliding with the argon atoms send out electrons that can be picked up by highly sensitive instruments placed on the detectors' fringes.

Once completed, the detectors will be installed 1,500m beneath the Earth in the Deep Underground Neutrino Experiment (DUNE) at the Sanford Underground Research Facility in South Dakota in the middle of the next decade.

"Studying neutrinos could provide answers to some major mysteries in physics, such as why is the Universe made entirely of matter and not antimatter," says CERN researcher Filippo Resnati. "We need a powerful neutrino beam and huge detectors if we want to measure and understand their properties."







EYE OPENER

Joyride junkyard

HEFEI,
CHINA

This vast sea of bicycles have been abandoned in a disused school playing field in Hefei, in China's Anhui Province.

The bikes started life as part of a number of shared cycle schemes, originally intended to ease the mounting congestion in China's bustling cities. Commuters could hire the bikes on demand using a smartphone app, then park them up when they'd finished their ride.

However, misuse of the system saw staggering numbers of the shared bikes discarded in precarious or obstructive places, such as narrow pavements, meaning many have had to be removed by the local authorities.

Now, over 10,000 confiscated bikes have accumulated in the school field, inadvertently creating the striking aerial artwork illustrated here. Hefei's city council will now begin the laborious task of returning the bikes to their respective companies.

PHOTO: EYEVINE



REPLY

Your opinions on science, technology and *BBC Focus*

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MESSAGE OF THE MONTH

VINYL SCHMINYL

If vinyl and vinyl turntables had been invented after CDs, we'd never worship them as we do now, because the sound of vinyl is actually a learned preference, rather like singing in the bath (we all sound like top operatic stars there). Humans love echo in the musical notes they listen to, and they love the spacious sound of good quality vinyl turntables.

However, this is actually an echo caused by a variety of errors in the way vinyl records are made. There is a small amount of the total signal present in the groove being traced by the stylus, which actually belongs to the preceding and succeeding groove. This causes what is known as pre- and post-echo. This echo is then read by the human ear as spaciousness. CDs do not have these artificial effects and are deemed to be flat-sounding in comparison with vinyl, because they lack the errors which combine to produce the sound we like.

LPs have other built-in faults which we've got used to because we grew up with them, like tracking error. The optimum angle of the stylus in the groove is only actually correct at one place on the disc: everywhere else it's slightly wrong but we have learned to ignore it. The same goes for bias correction. LPs are also notorious for generating wow if records are warped enough or the belt worn, and rumble if the turntable is not of high enough quality.

It's quite tiring to hear people go on about the superiority of vinyl when it's actually the inferiority they are talking about, but of a kind which they like. I like CDs if only for their durability and absence of extraneous sounds. I suppose, in the final analysis, there is no black art associated with CDs whereas with LPs humans can indulge their passion for one-upmanship in dissing other people's systems!

Roger Britton, via email



You are correct in saying that every medium has its own sonic 'footprint', defined by a variety of factors including the manufacturing process. The same is true of CDs, of course, which contain music encoded digitally at lower resolution than was possible when the format was invented in the early 80s, let alone today. This too contributes to the 'clean' sound beloved of CD diehards, which is actually an incomplete picture of the original music with much of the harmonic information lost. But then 'sound' only exists in our brains anyway – ain't nothin' going on but pressure waves otherwise – and psychoacoustics is a dark and winding rabbit hole to wander down.

The most important question is always, does it sound good to you? As a side note, both my own setups at home – the listening one and the DJ one – include vinyl, CD and digital channels, all of which are used regularly! – **Russell Deeks, contributing editor**

WRITE IN AND WIN!

The writer of next issue's *Message Of The Month* wins a super cute

Sphero Mini. This tiny, robotic ball can be driven around, used to play games, or programmed using its accompanying app. You can set up an obstacle course using its included cones and skittles, and even drive it using facial recognition! sphero.com



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BETWEEN THE LINES

Further to Robert Matthews' piece (October, p23), current education also provides an example of Goodhart's Law – and its consequences. As Robert says, the Law states: "If you choose a part of a system in order to measure the effectiveness of the system, it will cease to do so."

What part of education can be isolated in order to measure its effectiveness? Knowledge. So how can knowledge be measured?

1. Everyone needs to have acquired the same knowledge: this is a national curriculum.
2. Everyone needs to be measured equitably, therefore teachers need to know *how* the curriculum is going to be measured.
3. They also need to know that unless they teach the curriculum in a manner that conforms with the means of measurement, they will be judged to have failed.
4. The means of measuring the system has now become the system, and education is now examination.
5. Progress now consists of extending the measuring system from government departments to the smallest rural nursery. 'Educationalists' devise ever more sophisticated tests from four years to adulthood, and expanding teams of inspectors are sent in to monitor the application of these tests.

And the results? Parents, pupils and teachers are not as effective as they should be. As philosopher Bertrand Russell said: "Ends are no longer considered; only the skilfulness of the process is valued. This also is a form of madness."

Unfortunately, given the sheer size and cost of the system, who'd dare to suggest that it doesn't work?

Philip Hampson, via email

POWER TO THE PEOPLE

Yet again I find myself puzzled by the visualisation of 'two black holes warping space-time'. (November, p40). Surely this standard 'heavy object on rubber sheet' demonstration of the effect only makes sense if the rubber sheet is on Earth or in some other gravitational field? Help me, someone!

However, I applaud Erik Verlinde's work. Science is inductive and inherently arrogant. We have become conditioned to accept theory as fact, when in truth we have barely begun to understand the true nature of our Universe. Albert Einstein and Isaac Newton's brilliance is unquestioned, but their theories shouldn't be.

I would like to make the case that academic scientists don't have a monopoly on the intuitive understanding of such things. Something that many, many readers of *BBC Focus* will agree with!

Philip Hampson, via email

As with so many phenomena in advanced physics, any analogy for the effect of matter on space and time has its limitations, but the rubber sheet analogy does a reasonable job of capturing what Einstein's equations are saying. Questioning existing theories is vital, but history shows that 'intuitive understanding' is an unreliable guide to better theories. After all, who would have



Hemp could be used to make biodegradable plastics, says Peacemaker

guessed that pressure as well as mass is a source of gravity, as Einstein's theory demonstrates? – **Prof Robert Matthews, BBC Focus science consultant**

DOWN THE TUNNEL

In answer to Amy Rouse's letter (November, p12) regarding cortical hyper-excitability and dyslexia: your experiences sound much like mine (only more dramatic) and, yes, there are some links. People with dyslexia are more susceptible to pattern-glare than others and this is thought to be due to cortical excitability. This excitability is implicated in the origin of OBEs, tunnels and other aspects of near-death experiences, as well as in migraines, although cortical excitability is hard to measure.

There is recent evidence that OBE-ers suffer more from pattern-glare but as for dyslexia and OBEs – that's clearly one for future research. I know of no evidence yet on this possible connection.

Prof Susan Blackmore, OBE expert

ALL HAIL HEMP

A quick point on plastic (November, p52): I didn't see anything regarding the use of hemp. All plastics can be replaced with hemp-based plastic that IS biodegradable. There is a shift in attitude in the US as a new industry seems to be emerging regarding the use of hemp-based plastics and paper. I'd like to see a piece on it in a future edition.

Peacemaker, via Twitter



FOCUS

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Tails of the unexpected

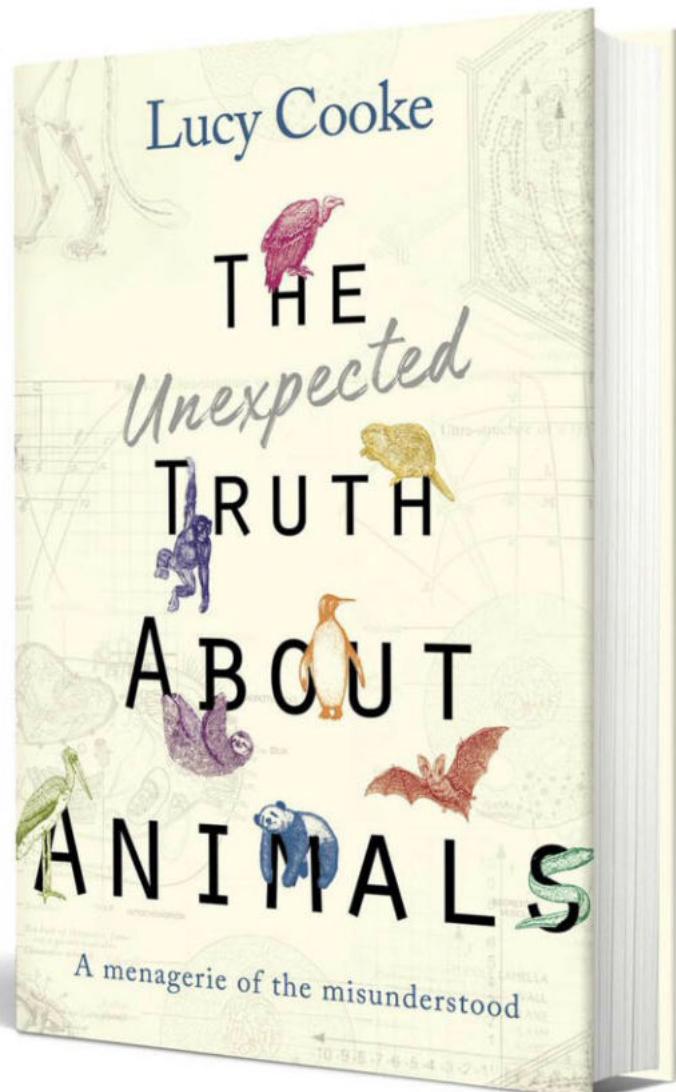
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DECEMBER 2017

EDITED BY JASON GOODYER

PHYSICS

NEUTRON STAR COLLISION SHAKES THE UNIVERSE

Discovery using gravitational waves opens up new chapter in astrophysics



Artist's impression of two merging neutron stars, with a burst of gamma rays erupting from them

For the first time in history, researchers at LIGO (Laser Interferometer Gravitational-Wave Observatory) in the US have used gravitational waves to observe a pair of neutron stars slamming into each other in the far reaches of space. The huge explosion, known as a kilonova, wobbled the fabric of space itself, sending gravitational waves and vast plumes of gamma rays and gold spraying out into the Universe.

The two LIGO detectors, based in Louisiana and Washington, and its sister facility, Virgo, near Pisa, Italy, recorded the remnant cores of two massive stars, around 1.1 to 1.6 times the mass of the Sun, spiralling toward and then smashing into each other some 130 million light-years away.

At the same time, a burst of gamma rays was detected by NASA's Fermi space telescope. Shortly afterwards, dozens of traditional telescopes around the world were trained on the aftermath of the explosion, making it the first cosmic event to be observed using both gravitational waves and light.

"Our background analysis showed an event of this strength happens less than once in 80,000 years by random coincidence, so we recognised this right away as a very confident detection and a remarkably nearby source," said LIGO's Prof Laura Cadonati.

"I EXPECT THAT THIS
DETECTION WILL BE
REMEMBERED AS ONE
OF THE MOST STUDIED
ASTROPHYSICAL EVENTS
IN HISTORY"

"This detection has genuinely opened the doors to a new way of doing astrophysics. I expect it will be remembered as one of the most studied astrophysical events in history."

Around 130 million years ago, the two neutron stars were in their final moments of orbiting each other, separated only by about 300km and rapidly gathering speed. As they spiralled faster and closer together, they stretched and twisted the surrounding space-time, radiating energy in the form of powerful gravitational waves, before finally smashing into each other.

At the moment of collision, the two neutron stars merged into one ultradense object, blasting out a 'fireball' of gamma rays. Subsequent observations using spectroscopy, which determines the presence of different elements according to the frequency of light they reflect, showed that around 200 Earth-masses of gold and 500 Earth-masses of platinum

were created in the collisions and subsequently distributed throughout the Universe.

In the coming months, telescopes will continue to observe the afterglow of the neutron star merger and gather further evidence about its interaction with its surroundings, and the processes that produce the heaviest elements in the Universe.

"This detection opens the window of a long-awaited 'multimessenger' astronomy," said David H Reitze, executive director of LIGO. "It's the first time that we've observed a cataclysmic astrophysical event in both gravitational waves and electromagnetic waves – our cosmic messengers. Gravitational-wave astronomy offers new opportunities to understand the properties of neutron stars in ways that just can't be achieved with electromagnetic astronomy alone."

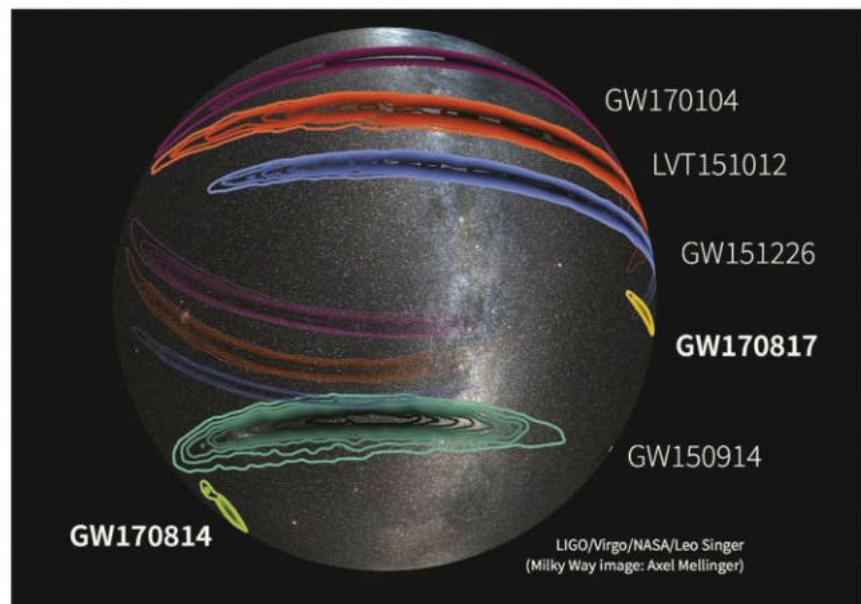
EXPERT COMMENT

Prof Brian Cox

Royal Society Professor for Public Engagement in Science

"This is a very exciting discovery for two reasons. First, it confirms yet again that Einstein's General Relativity, published 101 years ago, is a supremely precise description of space and time, gravity and the evolution of the Universe. This result is a highly non-trivial prediction, and it is a triumph of high-precision experimental physics that such subtle shifts in space-time at the level of a millionth of the size of an atom have been detected. Second, and even more excitingly, this opens up an entirely new way of observing the Universe. We can now observe collisions between black holes, probing gravity in ever more exotic and extreme situations, and look back in time far closer to the Big Bang than ever before. Gravitational wave astronomy opens up an entirely new window on nature."

Sky map of neutron star collisions observed by LIGO from 2015. GW170817 is the one that was detected most recently



WHAT HAPPENS WHEN TWO NEUTRON STARS COLLIDE?

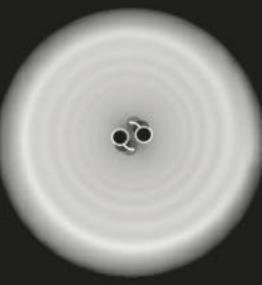
WHAT ARE GRAVITATIONAL WAVES?

Gravitational waves were originally theorised to exist by Albert Einstein more than 100 years ago. The waves are created when massive objects moving at high speeds send invisible ripples through the fabric of space, like ripples in a pond when a stone is tossed in. They travel at the speed of light and squeeze and stretch anything in their path as they pass by.

They were first detected in 2015 when LIGO (Laser Interferometer Gravitational-Wave Observatory) picked up ripples created by a pair of black holes that collided 1.3 billion years ago. The team behind the observation were awarded this year's Nobel Prize in Physics.

WHAT IS A NEUTRON STAR?

A neutron star is the remnant core left behind after a massive star around 10 to 30 times the size of the Sun explodes in a supernova. They are called neutron stars as they are believed to be composed almost entirely of neutrons – subatomic particles with no electrical charge. They are only around 20km across but their matter is packed so densely that a single teaspoon of material would weigh one billion tons on Earth.

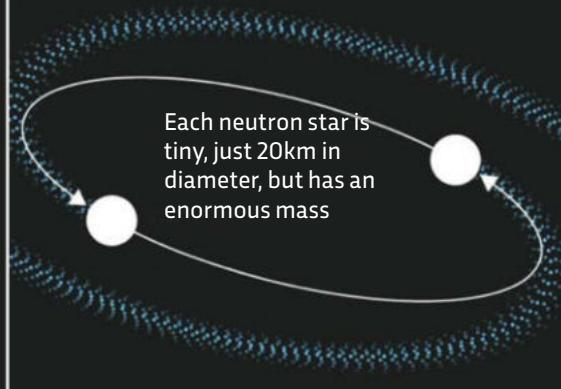


CATCHING A WAVE

Einstein's General Theory of Relativity tells us that if two massive objects, such as two black holes, are bound together by gravity, they should create ripples in the fabric of space-time. These ripples are called gravitational waves.

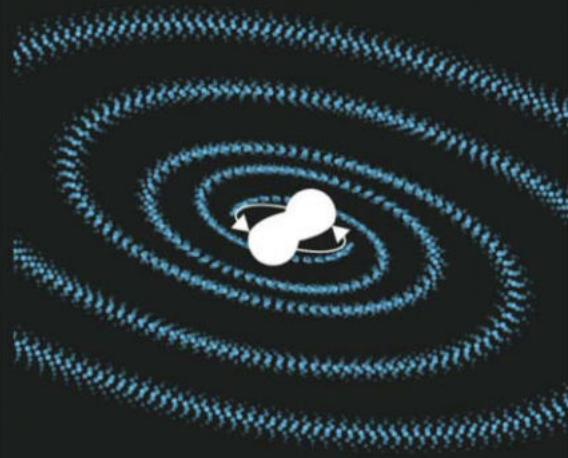
Orbit

Two neutron stars orbit each other 30 times every second. This distorts space-time.



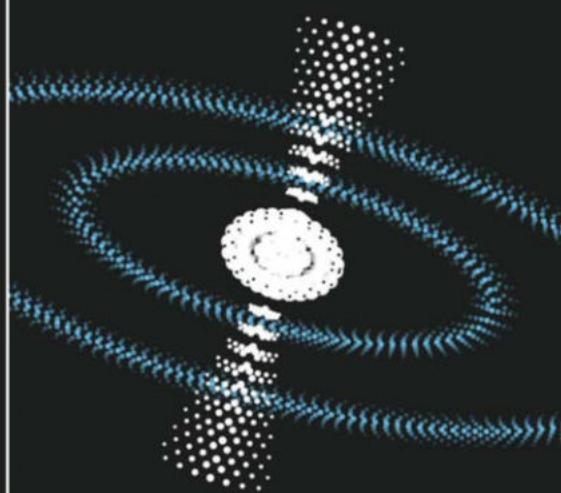
Distortion

The stars start to orbit faster and faster as they get closer together. They begin to distort due to the enormous amounts of gravity.



Collision

After a tiny pause, the stars energetically merge together, and blast out a plume of gamma rays.



Afterglow

A new light is spotted in the sky – an afterglow of the collision. This is a source of gamma rays and gravitational waves.

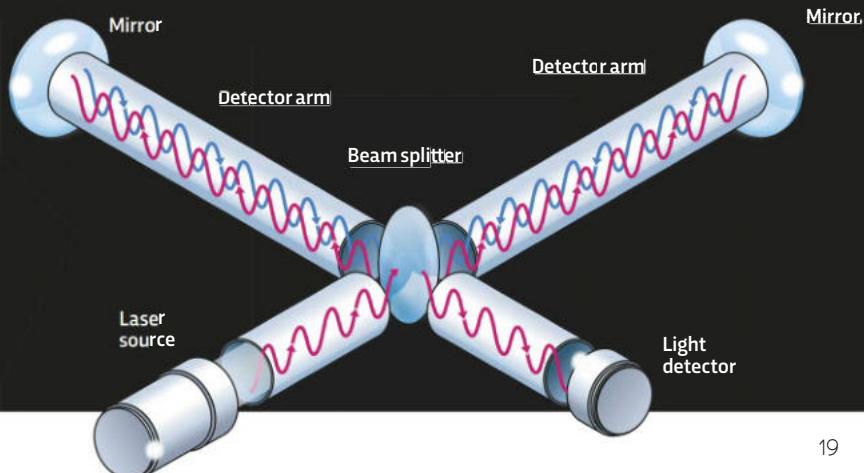
It is likely that the neutron stars collapsed to form a black hole



Evidence of heavy elements discovered by scientists

THE LIGO EXPERIMENT

There are two LIGO observatories, which are located 3,002km apart. Each LIGO observatory consists of a laser source, two detector arms, each with a mirror at the end, and a light detector. The laser shines onto a beam splitter and is sent down the detector arms, which each measure precisely 4km in length. If light waves fall out of sync due to being affected by gravitational waves, then the resulting 'spillage' of light will be picked up by the light detector.





ZOOLOGY

SHRIMP DISCOVERY SHEDS NEW LIGHT ON EVOLUTION OF EARLY BRAINS

Mantis shrimp are pretty impressive little critters: they can punch their hammer-like claws so quickly that they can produce an underwater shock wave and have 16 different colour receptors in their eyes – humans have just three. Now, distinct structures known as ‘mushroom bodies’, which have previously only been found in the brains of insects, have been identified within the crustacean brains of mantis shrimps. As insects evolved from crustaceans millions of years ago, this suggests that such structures may have developed earlier than was previously believed.

“To find this structure in a crustacean is really exciting, because it suggests that it may have arisen in deep time: an ancient centre, retained for over half a billion years, to perform this function,” said the University of Arizona’s Prof Nick Strausfeld, who led the research.

In insects, mushroom bodies in the brain are known to be involved with memory and learning, and the new research suggests that mushroom bodies in the mantis shrimp brain carry out similar tasks. This was shown using a process called immunohistochemistry, whereby extremely thin slices of brain tissue are coated with antibodies that highlight the presence of the proteins involved in memory processes.

It is not clear, at this stage, whether mushroom body structures evolved in crustaceans first but were then ‘lost’ by most species and only retained in insects, or whether they evolved in crustaceans and insects after the two groups of creatures became distinct.

“The question we ultimately want to answer is ‘What was the earliest brain?’ Our research gives us an insight into an ancient brain structure,” said Strausfeld.

Mantis shrimps have incredible eyesight, and can see UV, visible and polarised light

SPACE

GIANT LAVA TUBE COULD PROVIDE A LUNAR HABITAT FOR HUMANS

Could this be the site of humanity's first home on the Moon? Scientists from the Japanese space agency JAXA have detected a large, open lava tube in the Marius Hills region of the Moon, prompting speculation that it could be used as a base and shelter for astronauts on any future manned lunar missions.

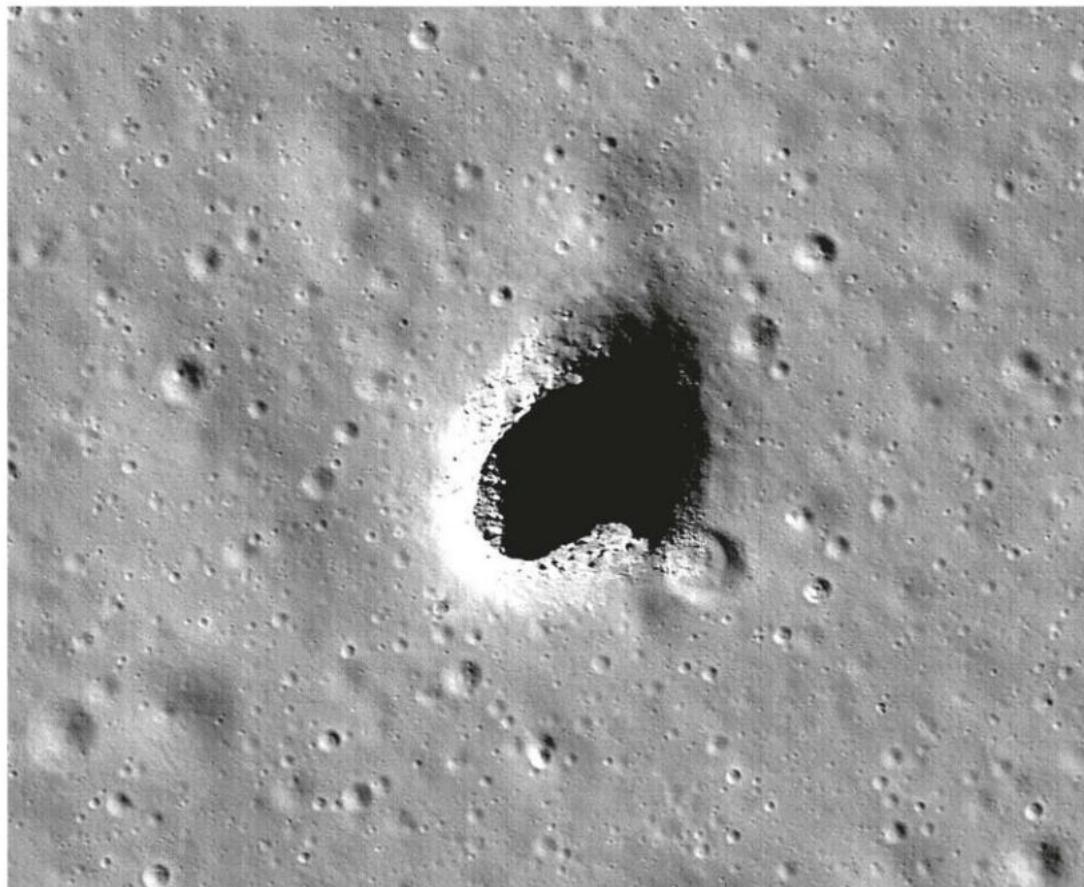
The time astronauts can spend on the lunar surface has always been very limited, as spacesuits can only protect the wearer from the radiation and extreme temperatures for so long. It has been suggested that lava tubes – long, tunnel-like caves formed by volcanic activity – could offer a solution to this problem, providing a more sheltered environment in which to build a lunar base.

Lava tubes form when the top layer of a molten lava flow cools and hardens while the lava below is still flowing. Such caves are

quite common on Earth, and have also been identified on the Moon, Venus and Mars. But the lava tube found by JAXA is one of the biggest yet discovered, having a 'mouth' that's more than one kilometre wide, and extending several kilometres below the lunar surface. The JAXA team made their discovery by collating data from NASA's GRAIL mission, which is building a detailed gravity map of the Moon, and its own SELENE spacecraft, which uses radar to study lunar geology.

"It's important to know where and how big lunar lava tubes are if we're ever going to construct a lunar base, but knowing these things is also important for basic science," said senior JAXA researcher Junichi Haruyama. "We might get new types of rock samples, heat flow data and lunar quake observation data."

The lava tube in the Moon's Marius Hills



IN NUMBERS

48

The number of Nobel Prizes awarded to female researchers. The remaining 833 have all been awarded to males.

35

The amount, in kilograms, of plutonium 238 held in reserve by NASA. The radioactive substance was used in the 'nuclear batteries' used to power deep space missions such as Mars Curiosity Rover or Voyager but supplies have now dwindled, leaving enough for just a handful more missions.

17

The number of different facial expressions horses use to communicate, as discovered by researchers at the University of Sussex.



NEUROSCIENCE

MAGIC MUSHROOMS COULD HELP IN THE TREATMENT OF DEPRESSION

Psilocybin, the active ingredient in so-called 'magic' mushrooms, can dramatically reduce symptoms of depression in patients who have failed to respond to other treatments, according to new research carried out at Imperial College London.

In the study, 20 patients who had experienced no benefits from more conventional depression treatments were given two doses of psilocybin: one of 10mg, and one a week later of 25mg – doses similar to those taken by recreational drug users. Almost half of the patients then reported a significant lessening of their symptoms.

"Several of our patients described feeling 'reset' after the treatment, and [they] often used computer analogies," said Dr Robin Carhart-Davis, who led the research. "For example, one said he felt like his brain had been 'defragged' like a computer hard

drive, and another said he felt 'rebooted'. Psilocybin may be giving these individuals the temporary 'kick-start' they need to break out of their depressive states."

This theory was backed up by brain images taken before and after treatment, which showed reduced blood flow to the amygdala (which processes fear, stress and anxiety), as well as greater stability in other areas of the brain.

"These imaging results do tentatively support a 'reset' analogy. Similar brain effects to these have been seen with electroconvulsive therapy," said Carhart-Davis.

Given the small sample size and the absence of a control group, the researchers stress that much more research is required – and they discourage anyone who suffers from depression from self-medicating until more is known.

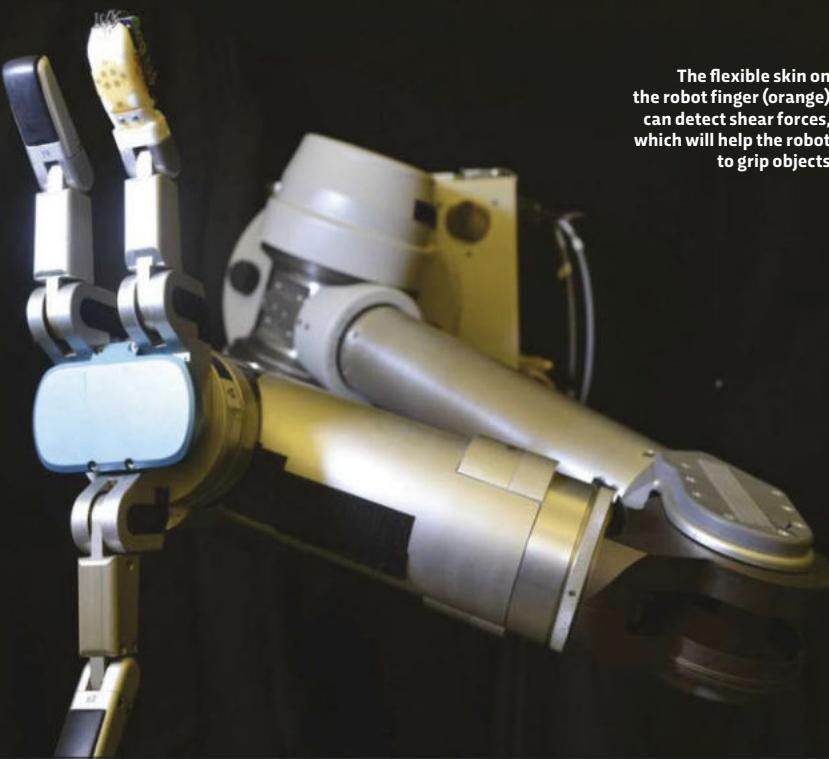
Numerous species of magic mushrooms grow naturally in many parts of the world. The ones pictured above are from Colombia. Magic mushrooms are a Class A drug – if you are concerned about drugs or drug use, visit talktofrank.com

ROBOTS

A FLEXIBLE SKIN CAN GIVE ROBOTS A SENSE OF TOUCH

Now this really could come in handy. A flexible, sensor-laden 'skin' that can be stretched over just about anything will give robotic devices a much more useful sense of touch. The new technology could be used both in prosthetics for amputees, and in factory-line and other working robots.

At the moment, pressure and other sensors enable a robot to 'know' whether it's holding an object or not, but it won't be able to tell if the object is slipping out of its grasp. This becomes a problem when, for instance, a robot surgeon doesn't realise it's dropping the scalpel – or when a Paralympian drops scalding hot coffee in their lap. The new 'skin' developed by researchers at the University of Washington and UCLA in the US gets around this problem, and is inspired by the touch-detection mechanisms of human fingers.



The flexible skin on the robot finger (orange) can detect shear forces, which will help the robot to grip objects

If you slide your finger from left to right across a surface, the skin to the left of your fingernail bulges out slightly, while the skin to the right tautens. The new silicone rubber skin mimics this, and has tiny channels, half the thickness of a human hair, embedded within it. These channels are filled with an electrically conductive fluid, and when the skin 'bunches up' as just described, the changes in the channels' geometry lead to a change in the resistance of the fluid within. By measuring these changes, the robot's 'brain' can detect shear forces and vibrations.

"By mimicking human physiology in a flexible electronic skin, we have achieved a level of sensitivity and precision that's consistent with human hands, which is an important breakthrough," said the University Of Washington's Prof Jonathan Posner.

THEY DID WHAT?!



FISHES' SERENADES SABOTAGED

What did they do?

A team at the University of Gothenburg blasted captive common gobies, fish that live in the coastal waters of Sweden, with simulations of leisure boat engine noise.

Why did they do that?

A male goby builds a nest out of empty shells to attract females. When a female comes to inspect it, the male sings a serenade to win her over. If the female deems the male to be suitable, she will spawn in the male's nest. As the use of leisure boats is growing, the team wanted to investigate the potential effects of noise on the mating habits of nearby marine life.

What did they find?

The fish in the noisy tank mated less, and took longer to mate, than the fish in a quiet aquarium.

GENETICS

"We are trying to understand ageing at a molecular level"

Calorie restriction can extend lifespan in mammals, but the mechanism is not clear. Research by Prof Jean-Pierre Issa of Temple University suggests it works through epigenetics

ABOVE: Diet may play a role in ageing thanks to the effect it has on the epigenome

What is epigenetics?

Our body has a single genome that we get from our father and mother. But we have more than 200 different cell and tissues, all derived from a single blueprint, the genome. So how do you generate different tissues from one book or blueprint?

The answer is a set of processes that we call 'epigenetics', because they work on top of genetics. They function like bookmarks that a cell uses to establish its cellular identity. They tell the heart, for example, which pages of the book it should use. We call them tags. Epigenetic tags can be molecules attached to DNA, or to the proteins around which DNA is wrapped, and just as you can sequence [read] the genome, you can sequence the entire 'epigenome'.

How do these tags affect the ageing process?

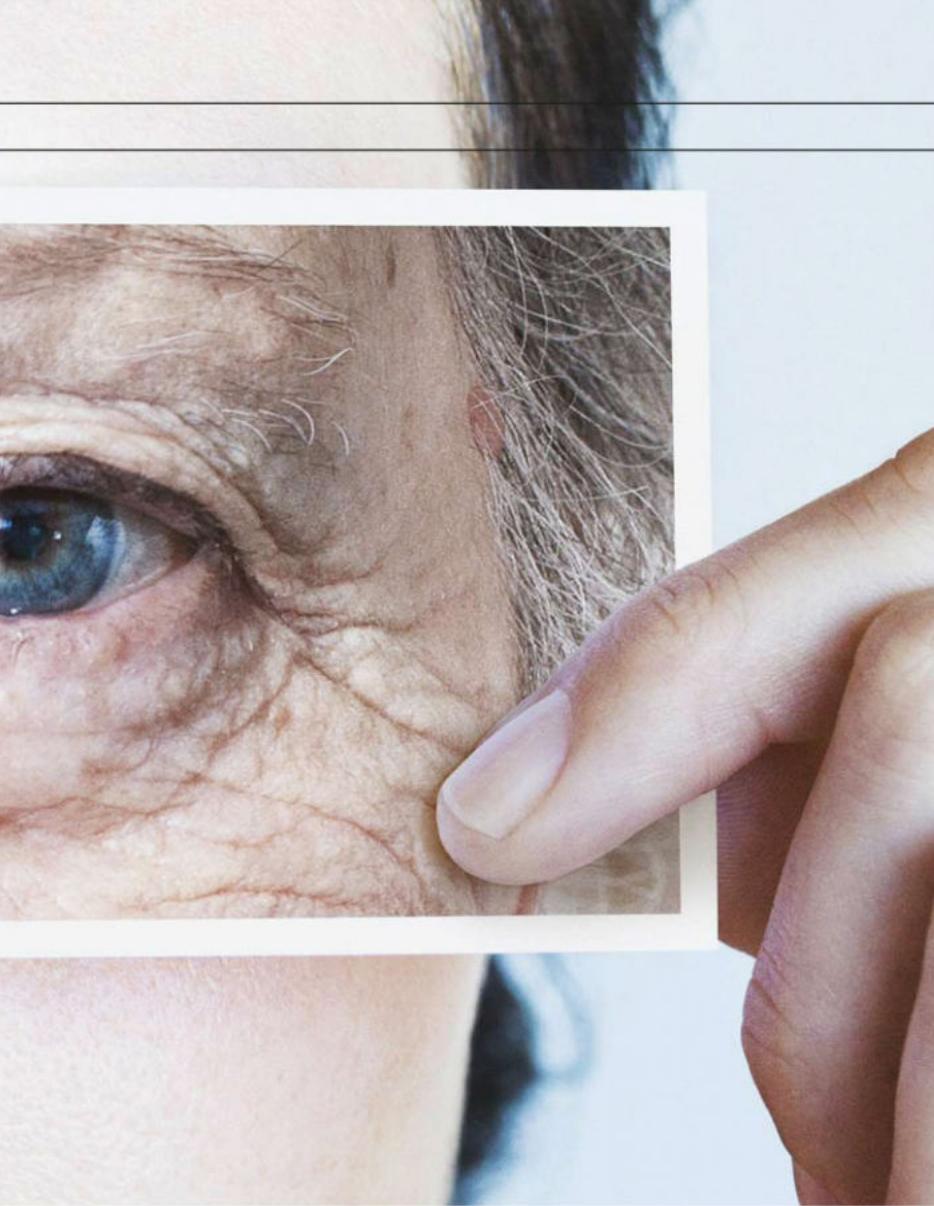
As we age, bookmarks get reshuffled. Some disappear and others appear where they shouldn't. We call it 'drift' – an acquisition of noise in the epigenome. I believe it's a feature of ageing in all mammals, but we've only studied three: mice, monkeys and humans. We find the rate of noise or drift – how quickly reshuffling occurs – is correlated with how long an organism lives. So

humans, who can live to 100-120, reshuffle their epigenome quite slowly, while mice, which live two to three years, reshuffle very quickly.

My work started with cancer, where bookmarks are extremely reshuffled. The idea that our bodies might have an 'epigenetic clock' – a molecular measure of how long we've already lived – came from studies my laboratory did more than 20 years ago, when we found that normal tissues also showed some reshuffling.

How is epigenetics linked to calorie restriction?

There aren't many things we know of that make us live longer, but calorie restriction is one. Half of monkeys were given a 'normal' diet, the other half were given 30 per cent fewer calories. Mice were exposed to 40 per cent calorie restriction, with the same volume of food but lower nutritious content. We saw a more profound effect in mice than in monkeys. Even within a species, we can alter how quickly an animal ages by calorie restriction, and that alters how quickly the epigenome is reshuffled. These two observations led us to the hypothesis that reshuffling explains, at least in part, why we develop diseases as we age.



Could you manipulate epigenetics to improve health?

One can measure the epigenetic clock and, if it's very fast, a person might be at particular risk for cancer and other diseases. One could institute preventative measures and screening.

Long-term, can we cure ageing? In the lab, we have the ability to reshuffle tags back to normal. If we were to develop a technology to rejuvenate tags in the stem cells of an old person, that could potentially make them live longer. But it's important to avoid the conclusion that we should

all start starving ourselves. We don't actually know calorie restriction will prolong life in humans, and the data in animals is more complicated than at first glance [due to] different genetic backgrounds. What we are doing is trying to understand ageing at a molecular level, and to develop interventions that will prolong life.

BELOW: Macaques fed a calorie-restricted diet live longer than those who can eat whatever they please



SAUNA-GOERS

Visiting a sauna regularly can lower the risk of suffering from elevated blood pressure by up to 50 per cent, researchers at the University of Eastern Finland have found. Looks like it's time to get a sweat on.

RED SQUIRRELS

The population of red squirrels at Wallington Estate in Northumberland is booming, after almost being wiped out by squirrel pox brought in by grey squirrels in 2011. The estate is now home to more than 150 individuals.

GOOD MONTH

BAD MONTH

SHARKS

Watch your back, Jaws! A researcher at Kansas State University has found the remains of sharks in the stomachs of alligators on the Florida coast. This is thought to be due to alligators venturing out into salt water following heavy rain.

LAZY SHOPPERS

Ordering groceries for home delivery rather than carrying them home from the shops is causing our muscles to waste away, a study by the Chartered Society of Physiotherapists has found. Such lack of activity can increase the risk of falls and other health issues, they say.





Bones from the fossilised remains of the tyrannosaur species

PALAEONTOLOGY

NEARLY COMPLETE TYRANNOSAUR FOUND IN SOUTHWESTERN USA

Palaeontologists have unearthed the almost complete fossilised skeleton of a tyrannosaur in the Grand Staircase-Escalante National Monument in southern Utah. The fossil is believed to be around 76 million years old and is most likely an individual of the species *Teratophoneus curriei*, one of Utah's ferocious tyrannosaurs that walked western North America between 66 and 90 million years ago during the Late Cretaceous.

The skeleton is six metres long and is thought to be that of an adolescent animal aged between 12 and 15 years old. The excellent condition of the skull has allowed researchers to note its relatively short head, unlike the typically longer-snouted look of tyrannosaurs found in the northern US.

"With at least 75 per cent of its bones preserved, this is the most complete skeleton of a tyrannosaur ever discovered in the southwestern US," said Dr

THE FOSSIL IS
BELIEVED TO
BE AROUND
76 MILLION
YEARS OLD"

Randall Irmis, curator of palaeontology at the Natural History Museum of Utah. "We are eager to get a closer look at this fossil to learn more about the southern tyrannosaur's anatomy, biology and evolution."

The fossil was first discovered in 2015 and was excavated over the last two years before being airlifted by helicopter to the Natural History Museum of Utah. Scientists believe that it was buried either in a river channel or by a flooding event on the floodplain, keeping the skeleton intact. Work will now begin on examining the fossil in more detail.

"We'll look at the size of this new fossil, its growth pattern, biology, reconstruct muscles to see how the animal moved, how fast could it run, and how it fed with its jaws. The possibilities are endless and exciting," said Irmis.

THINGS WE LEARNED THIS MONTH

'BROMANCE' TRUMPS ROMANCE

A team in Los Angeles has found that straight male university undergrads find their friendships with their male friends more satisfying than their romantic relationships with their girlfriends.

TROPICAL FORESTS ARE EMITTING MORE CARBON THAN OXYGEN

Thanks to continuing deforestation, the Earth's tropical forests are now emitting almost twice as much carbon as they consume, researchers at Boston University have found.

DOGS REALLY CAN SMELL FEAR

A team from Naples collected sweat from human test subjects who were shown videos designed to elicit fear or happiness. They then presented the samples to a group of dogs and monitored their heart rates and behaviour. The dogs exposed to the 'fear' samples showed higher heart rates and more unsettled behaviour.

A HUGE SOLAR FLARE COULD STRIKE THE EARTH WITHIN THE NEXT 100 YEARS

It looks like it could be time to start stockpiling tinned goods. Researchers at Harvard University say that a giant solar flare could strike the Earth in the next century.

SPACE

PLUTO'S PAL HAUMEA HAS A RING AROUND IT

Someone liked this dwarf planet so much they put a ring on it. Researchers in Spain have found that Haumea, one of the four dwarf planets located beyond the orbit of Neptune, is encircled by a planetary ring system.

It is the first time a ring has been discovered around a trans-Neptunian object, and it shows that the presence of rings could be much more common than was previously thought, in our Solar System as well as in other planetary systems.

"Until a few years ago we only knew of the existence of rings around the giant planets; then, recently, our team discovered that two small bodies situated between Jupiter and Neptune, belonging to a group called centaurs, have dense rings around them, which came as a big surprise. Now we have

discovered that bodies even farther away than the centaurs, bigger and with very different general characteristics, can also have rings," said researcher Pablo Santos-Sanz.

The team observed the ring by taking advantage of stellar occultations – instances when a planet becomes more visible as it passes in front of a star. According to the data, the frozen particles that compose the ring rotate three times slower around the planet than it rotates around its own axis.

"There are different possible explanations for the formation of the ring; it may have originated in a collision with another object, or in the dispersal of surface material due to the planet's high rotational speed," said researcher José Luis Ortiz.



Artist's impression of dwarf planet Haumea, with its ring system



We want to find out more about two fascinating sleep phenomena: exploding head syndrome and sleep paralysis. So we've designed a study that will investigate both.

This is a unique opportunity to take part in a piece of scientific research. This means you can choose to be one of the participants, or you can simply follow us online to learn about how scientists will analyse the data, find out what we've uncovered when the results are published and finally read the report in *BBC Focus*. If you enter there's a chance to win one of five Amazon vouchers, worth £100 each.

Have you ever been drifting off to sleep and found that you simply can't move? Or perhaps this has happened as you were waking up? During this experience, have you seen any strange things which aren't there when you're able to move again? Or perhaps you can't see anyone, but have had a strong feeling that someone or something is really there? Have you heard loud and jarring noises just as you were nodding off, or seen a bright flash or bolt of lightning? We caught up with sleep expert **Prof Alice Gregory** from Goldsmiths, University of London to find out more about these experiences...

What is exploding head syndrome and how common is it?

Exploding head syndrome involves the sensation of an explosion or loud noise when falling asleep or waking up. The experience might be similar to hearing the sound of a crash or a firework. While it can be alarming, it does not typically cause pain. The syndrome has been given this rather dramatic moniker, but some people, including one of our team, Dr Brian Sharpless, has been among those suggesting a new name: 'episodic cranial sensory shocks'. This syndrome might sound frightening, but actually it is pretty common. For example, in one report 18 per cent of college students reported having experienced symptoms of exploding head syndrome.

FOCUS
is conducting its very
first piece of research
together with Goldsmiths,
University of London
and we need your
help!



WE NEED YOU!

sciencefocus.com/bigsleepsurvey

“Sleep paralysis is more common than one might expect. In one of our studies, roughly a third of our participants reported experiencing sleep paralysis at least once”

What do we know about it?

There are many explanations for exploding head syndrome, but I won't go into these. That's because we want to know what people who have experienced these things think is going on, rather than what the experts believe might be happening.

Should I be worried if I have it?

Exploding head syndrome is considered to be pretty benign – and does not cause pain. However, some people have these experiences frequently and find them to be disturbing. If anyone is concerned, they should see a doctor who can rule out other disorders.

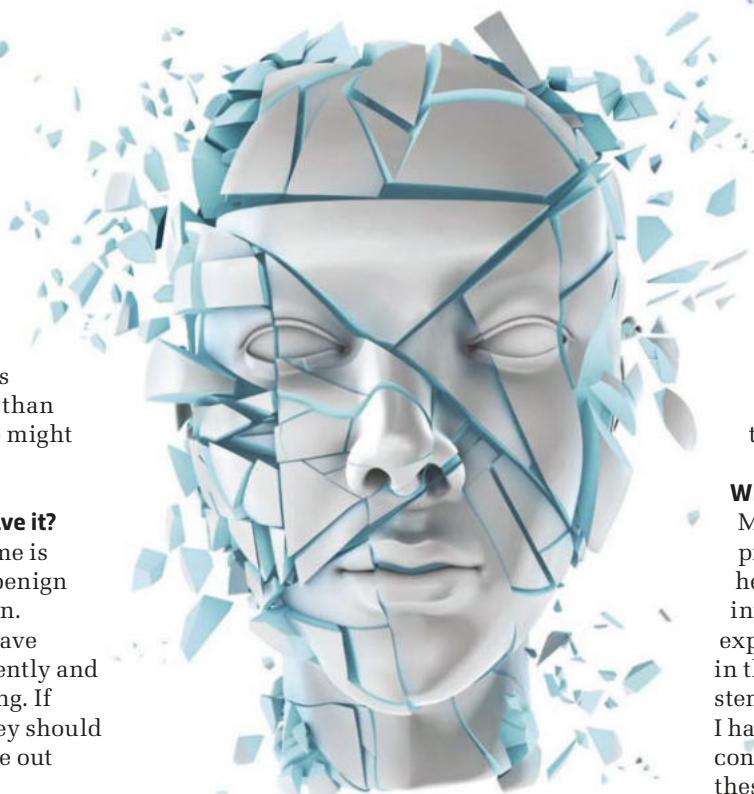
What does this study seek to find out?

While exploding head syndrome is relatively common, we know little about it. For example, if someone is having these experiences and wants advice on how to stop them, there is little information we can provide. Certain techniques are said anecdotally to help but there is little case-study evidence to back this up.

So we want to add to our limited knowledge in this area. For example, we want to understand more about the associations between sleep habits, beliefs and exploding head syndrome. In particular, we want to know how people try to prevent these experiences from occurring or to disrupt them once they do occur – and which of these techniques are most successful.

What is sleep paralysis?

Sleep paralysis is another fascinating sleep phenomenon. It involves being unable to move just as we are falling



asleep or waking up. It's often accompanied by perceptions which aren't there when movement returns.

How common is it, and what causes it?

Sleep paralysis is more common than one might expect. In one of our studies, roughly a third of our participants reported experiencing sleep paralysis at least once. In the same study we found that a number of factors were associated with sleep paralysis, but there's a lot more to learn.

What do you want to find out?

As with exploding head syndrome, we want to understand more about people's explanations for such experiences and also how people attempt to stop them from occurring or deal with them when they do so. One of our team (Prof Chris French) will also be building a database of those with sleep paralysis so that (with their permission) we can contact them about our future studies.

Why should I take part?

Nobody should feel obliged to take part. However, if you are interested in participating, we'd love to hear from you! Not only do we want to hear from those who have had these experiences, but we are just as interested in those who have not. We are keen to examine differences between those who have and have not had these experiences.

Who's involved?

My own research over the years has primarily focused on sleep and mental health. I have only recently become interested in sleep paralysis and exploding head syndrome. My interest in these under-researched topics stemmed from fascinating discussions I had with Chris, who has been contacted by lots of people who reported these symptoms.

Chris also introduced me to Brian, who is a leading expert on both exploding head syndrome and sleep paralysis (and based at Argosy University, Northern Virginia). Together – and with help from a superb post-doctoral student, Dr Dan Denis, who is based at Harvard Medical School – we have developed a programme of research investigating these under-researched topics. Students at Goldsmiths, University of London, are also keen to get involved where possible too.

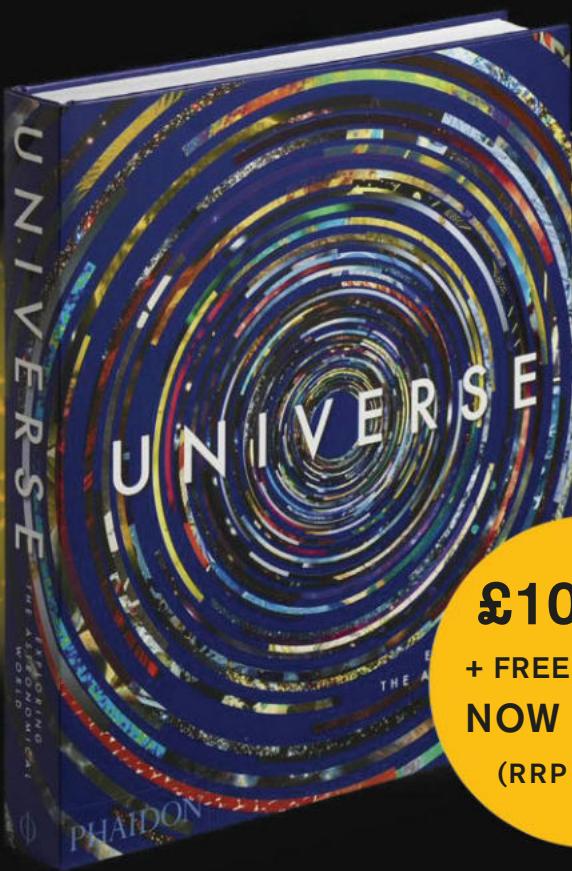
As with most research, this project is very much a collaborative effort. We hope that this project will not only result in interesting articles for *BBC Focus* magazine, but will produce data that will be publishable in scientific journals, and presented at conferences. It won't happen without readers getting involved, so we are grateful for your interest in the study!

Intrigued? Then the first step is to head to sciencefocus.com/bigsleepsurvey and take part in our survey!

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THE TRUTH IS (STILL) OUT THERE

New discoveries come thick and fast in science – but so do red herrings and blind alleys

When I started writing this column, back in the mid-1990s, science seemed on the brink of a new age of discovery. NASA's Hubble Space Telescope looked set to give astronomers unprecedented insights into the nature of the cosmos. Theorists were claiming to have seen glimpses of the ultimate Theory of Everything, describing all the particles and forces in the Universe. The Human Genome Project was homing in on our genetic blueprint.

So, 20-plus years on, how did it all pan out?

Not as expected, that's for sure.

The Hubble Space Telescope gave astronomers the cosmic data they craved – along with evidence that our Universe is controlled by dark energy, a kind of anti-gravitational force of unknown origin.

Theorists hoping to find the Theory of Everything (ToE) have ended up lost in a mathematical jungle, with no clear clue of where to go next.

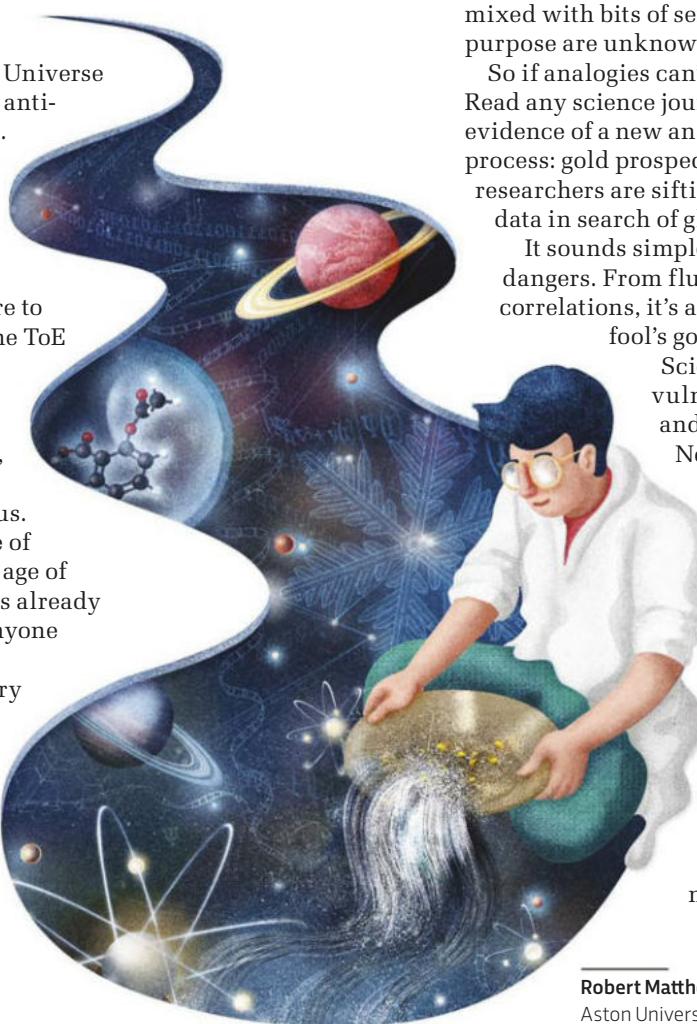
The Large Hadron Collider was supposed to have helped, but its failure to find any new particles predicted by the ToE has just made things worse. And the Human Genome Project succeeded in revealing the sequence of all three billion letters of our genetic blueprint, yet also showed that 98 per cent of them have no clear role in producing us.

There's a theme here, but it's not one of failure. We are indeed living in a new age of discovery, and the biggest revelation is already in: reality is far more complex than anyone thought even 20 years ago.

We're at a turning point in the history of science. For centuries, we've been able to make sense of reality through analogies and simplifications. The cosmos was once thought to be a series of perfect spheres centred on the Earth, while atoms are to this day still sometimes portrayed as tiny solar systems.

Such analogies do work – up to a point. The trouble is that now we're having to grapple with situations for

"REALITY IS FAR MORE COMPLEX THAN ANYONE THOUGHT EVEN 20 YEARS AGO"



which analogies are not just hard to come by, but often flat-out misleading.

There's simply nothing in our everyday experience like dark energy, for instance. It just emerges out of nowhere, its repulsion too weak to detect except on cosmic scales. The search for the ToE has led to a new vision of subatomic particles as multiple-dimensional objects comprehensible only through mathematics. And thinking of our genome as a 'book' for building humans has proved hopelessly simplistic. Parts of it makes sense but most of it now appears to be gibberish, mixed with bits of sense whose length and purpose are unknown.

So if analogies can't be relied on, what can? Read any science journal, and you'll find evidence of a new analogy for the scientific process: gold prospecting. Using computers, researchers are sifting through mountains of data in search of gleaming nuggets of insight.

It sounds simple, but it's fraught with dangers. From fluke results to misleading correlations, it's astonishingly easy to find fool's gold in raw data.

Science has always been vulnerable to wishful thinking and evidence pushed too far.

Now more than ever we need to be on our guard for 'insights' that are anything but!

This is my final column for *BBC Focus*, and it's been a privilege to write for the magazine for so long. But in the end, the motto of the Royal Society says everything I've tried to say in just three words that have never been more relevant.

Nullius in verba – take no one's word for it. 

Robert Matthews is visiting professor of science at Aston University, Birmingham.



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A WORD IN YOUR EAR?

The most interesting thing about Google's recent Pixel 2 smartphone launch was actually one of the accessories. These Pixel Buds work with Google Assistant and Google Translate and claim to offer real-time translation of 40 different languages. They're available from November, and you don't necessarily need a Pixel 2 to use them – any phone running Android 6.0 or above will do.

No units have been made available for testing, so how well they'll work remains to

be seen. Translating spoken language – with all its umms and errs, rough-and-ready syntax and idiomatic expressions – is harder than translating written text, and reliance on automated systems has led to some famous blunders in the past.

So will Google's Pixel Buds be a real-life version of the iconic Babel Fish from *Hitchhiker's Guide To The Galaxy*, or a Google Glass-like disaster? We can't wait to find out...

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1



2



3



4



5



WANTED

1 FIRE IT UP

Camp out in style with this combined smokeless camping grill and fire pit, which features a Bluetooth-controlled air injection system that can be charged up either from the mains, or using the solar panel on the optional carry-case.

BioLite FirePit

\$200 (£155 approx), bioliteenergy.com

2 POCKET CINEMA

The size of a drinks can, this Bluetooth/Wi-Fi speaker and video projector features five internal speakers, plus HDMI and USB ports to hook up non-streaming sources. The picture's only 854 x 480 pixels, but beats watching films on your phone!

Anker Nebula Capsule

\$350 (£265 approx), seenebula.com

3 SMARTER SOCCER

Want to improve your footy skills? Place your iOS/Android on the supplied tripod, pair it with this smart football and its camera will track the ball as the app guides you through over 100 training drills and gives feedback on your performance.

DribbleUp Smart Soccer Ball

\$89.99 (£69 approx), dribbleup.com

4 TWO FOR ONE

These noise-cancelling headphones combine the high-fidelity sound KEF is known for with luxuriant styling courtesy of Porsche. Already winning design awards, they're available in both wired and wireless (Bluetooth) versions.

KEF Space One

£300/£349, kef.com

5 WEE 64

We've seen miniature versions of the ZX Spectrum and the Nintendo SNES console, and now nostalgic C64 owners can get in on the craze with this 1:2 scale reproduction, complete with wired joystick, USB ports and 64 pre-installed classic games.

C64 Mini

\$70 (£55 approx), theC64.com

6 SECRET SMARTS

What you see here is an ordinary Timex watch – it's the strap that's the clever bit. Hidden inside is a Barclaycard bPay chip, enabling you to make payments without needing a full-blown smartwatch. bPay straps will soon be available separately.

Timex Fairfield Contactless

£159, timex.co.uk

6



SATELLITES CAN PREDICT MALARIA OUTBREAKS

A new technique using images from NASA satellites may offer hope in the battle against malaria, allowing scientists to predict where outbreaks are likely to occur months before they actually happen.

Malaria remains a serious threat in the 21st Century. In 2015 there were 296 million cases worldwide, resulting in 730,500 deaths. Around 90 per cent of cases occur in Africa, where the disease is estimated to cost local economies around \$12bn each year.

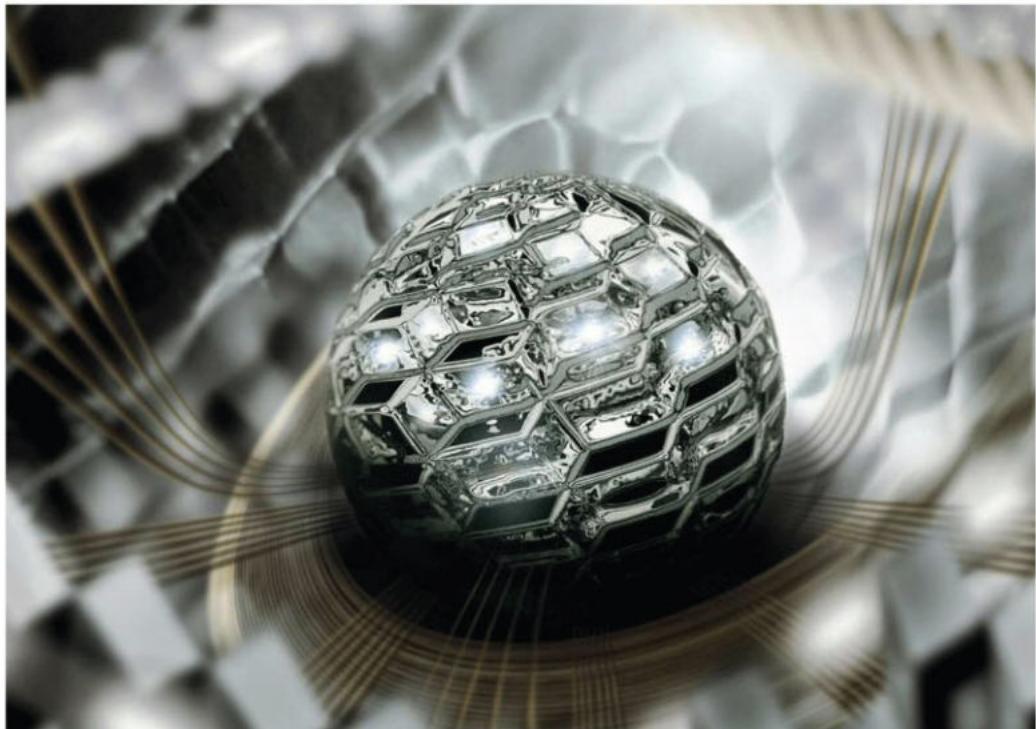
The new technique has been developed by a team led by William Pan, an assistant professor of environmental health at Duke University in the US, working in association with NASA's own Applied Sciences Program and the government of Peru. It involves using images from NASA satellites to monitor precipitation patterns worldwide, then

combining this information with land-surface modelling data to build up a detailed picture of where the puddles and ponds that malaria-carrying mosquito species need to lay their eggs are likely to form. Crucially, this can be done before they actually do form, enabling local health organisations to distribute mosquito nets, sprays and medicines in the right areas *before* an outbreak occurs.

Ben Zaitchik, an associate professor in the Department of Earth and Planetary Sciences at Johns Hopkins University in Baltimore, who was involved in the land-surface modelling aspect of the research, said: "It's an exercise in indirect reasoning. These models let us predict where the soil moisture is going to be in a condition that will allow for breeding sites to form."

The one-celled *Plasmodium* parasite that causes malaria is picked up and spread by mosquitoes when they feed on humans





Visualisation of a crystal core of a quantum computer

COMPUTING

MICROSOFT DEVELOPS A CODING LANGUAGE FOR QUANTUM COMPUTERS

While there's much talk of the enormous potential of quantum computing, the computers themselves are, in reality, still some years away. But that hasn't deterred Microsoft from developing a coding language to program them.

Microsoft is also, of course, working on building the machines, with mathematician Michael Freedman heading up a team of (in Microsoft's words) "some of the world's pre-eminent condensed-matter and theoretical physicists, materials scientists, mathematicians and computer scientists". But in the meantime, individual researchers and companies can now visit the Microsoft website to access a set of software tools that will enable them to write simulated routines to solve problems requiring up to 30 or 40 logical qubits – the fundamental 'building blocks' of quantum processing – respectively.

There's a bit of a catch here, because the most powerful quantum computer yet built, an IBM machine, is only a 17-qubit machine. But Microsoft wants to be ready for the day when functional quantum computers do arrive, just as it developed the BASIC programming language before the first personal computers became available back in the mid-1970s. And Microsoft certainly isn't alone in thinking this way. IBM, which is working on a quantum computer of its own, recently released an API for software developers called the IBM Quantum Experience.

Dr Krysta Svore, research manager at Microsoft Research's Quantum Architecture and Computation Group, said: "Quantum computing will allow us to solve problems that currently take longer than the lifetime of the Universe in seconds, hours or days."

TECH BYTES

DEUS EX MACHINA

Anthony Levandowski, who used to head Google's self-driving car project, has set up his own religion. Way Of The Future's stated aim is "to develop and promote the realisation of a Godhead based on artificial intelligence." Er, okay...

**PIRACY RULES, OK?**

An EU study, completed in 2013 but only just published, found no evidence that online piracy actually harms sales of music, movies and games – except in the specific case of 'blockbuster' movies.

WE INTERRUPT THIS PROGRAMME...

Late September saw TV broadcasts in California interrupted by strange apocalyptic messages about aliens and "extremely violent times [to] come", in a move reminiscent of the cult film *They Live*. No explanation has yet emerged.

USB SNIFFER DOGS

Devon & Cornwall Police have trained two sniffer dogs to locate hidden USB sticks and SD cards, in a bid to help combat terrorism and the distribution of child abuse images. The two dogs are now available 'on loan' to forces across the UK.

TECHNOLOGY

NATIONAL THEATRE TRIALS MIXED REALITY SUBTITLES

The world of theatre probably isn't the first place you think of when it comes to cutting-edge technological innovation, except maybe in the special effects department. But think again, because London's National Theatre is currently trialling a new mixed reality system, called Open Access Smart Capture, to provide subtitles for the hard of hearing at all its performances.

Subtitles have actually been available at the National Theatre for some time, displayed in the form of LED screens placed at the side of the stage. But these screens are distracting for the audience, and hence are employed only for a handful of performances. The mixed reality headsets currently on trial, on the other hand, mean that deaf or hearing-impaired theatregoers can attend any performance they choose.

The spectacle-like mixed reality headsets work by projecting subtitles directly onto the user's retina. From the wearer's point of view, the subtitles appear to float in the air on-stage, and they can be moved around using a hand-held remote so as not to obstruct the view. This also solves the problem presented by the existing LED system, whereby hearing-impaired visitors' eyes must constantly flick back and forth between stage and screen.

The Open Access Smart Capture system has been developed with technology solutions provider Accenture, and printing and imaging specialists Epson. It's being tested in the Dorfmann Theatre, one of three that make up the National Theatre complex, but it's hoped that later in the trial it will be available in all three theatres.

The glasses allow deaf theatregoers to watch shows without having to look at a subtitled screen



Rufus Norris, artistic director of the National Theatre



Olivia Colman (right) and Olivia Williams at the demonstration for Open Access Smart Capture



The subtitles are projected onto the watcher's retinas, and can be moved with a remote control

TEST

HEADPHONES REINVENTED

This groundbreaking device claims to tune your audio to your hearing – does it work?

The Nuraphones are something to be cherished: a genuinely new take on a piece of technology that's been around for over a century. Nura's pitch is that our ears are all different, but headphones are all the same. They're not talking about the shape of our ears, but about our sensitivity to sound frequencies. Traditional headphones ignore this, but the Nuraphones test your hearing and configure your audio output to remedy any nuances in the way your auditory system perceives sound. For example, I might be more sensitive to low pitch, bassy sounds, meaning that they tend to drown out anything in the treble spectrum. On an equaliser you might find me sliding up the treble. But my partner could be more attuned to treble, finding my changes tinny and lacking bass.

SOUND IDEA

Here's the smart bit. The Nuraphones work by testing something called the 'otoacoustic response'. When you hear a sound, your inner ear (everything past the eardrum, more specifically the cochlea) actually makes a sound back. It's a tiny, minuscule sound, but it's a response from your inner ear's hair cells – these are the little filaments that vibrate in response to sounds entering your ear, translating soundwaves into electrical signals that are sent to your brain. This otoacoustic response is a measure of the condition of these vital hair cells. When the cells are damaged, you lose sensitivity to certain frequencies – sometimes we hear this as tinnitus. This test is most commonly used to check hearing in newborns, since it can measure your auditory sensitivity without words.

That, in part, explains the unusual design of the Nuraphones. To take a measurement of the otoacoustic response, the headphones need two things: silence and proximity. The outer cup seals off noises from the outside world, while the in-ear protrusion puts a sensitive microphone close enough to your inner ear to whisper its prescription. A microphone, by the way, that the creators tell me has been bought by NASA for use in future Mars Missions. ●

NURAPHONES

PRICE: £349
uk.nuraphone.com



DO THEY WORK?

The short answer is yes, it seems so. Turn on the app, put your name in, position the in-ear phones correctly and the app greets you by name. A minute later, the hearing test is over and the Nuraphones have stored your profile (you don't need the app to make the headphones work, just to change between profiles). The Nuraphones then play you a sample through the filter mapped from your unique hearing sensitivities. You can turn it on and off to hear the music with and without Nuraphones' adjustments.

The effect is almost magic. You can tap your right earphone to cycle the filter on and off, and the difference is so compelling that I spent my week with the Nuraphones revisiting my music library. The sound just feels more nuanced, letting the more delicate elements of your music shine through. It's something akin to what happens when you wear sunglasses: you're no longer blinded to the overwhelming amount of light and suddenly everything gains more clarity. Recordings feel more spacious. Since you're more attuned to the audio's levels you get a sense of space and direction, like the music's being played in front of you. This effect is boosted by the 'immersion mode' which sends extra bass through the cans, rather than the in-ear speaker. This can turn the bass up so high that it actually shakes the headphones on your head to give you a sort of haptic bass effect. Since it's coming from a separate speaker, it manages this without distorting the rest of the sound.

A cynic might question the starkness between the 'with' and 'without' filter modes. Standard headphones at Nuraphones' price range don't sound as bad as the 'off' setting on the Nuraphones might have you believe. Instead the real measure, in my opinion, of what the Nuraphones are doing is what happens when you try out other people's aural profile. My partner's audio was turned up massively in the treble range, it was like the album we were listening to – *Pet Sounds* by the Beach Boys – had been put through a magic mirror at a funfair.

TUNED UP

The Nuraphones started life as a Kickstarter project, developed in a dialogue with their first buyers. This means every design choice



The silicone earcups are not noise-cancelling, but they do offer decent isolation from your environment



In this cross-section, you can see how the bass speaker is separate from the in-ear bud



has been painstakingly considered. For a start, the packaging is compostable (made out of potato, actually). The materials used, from the brushed aluminium body to the silicone earcups, have all been carefully selected to be the same shade of matt black. Since Nura chose silicone for the earcups, they built in a Tesla valve – a valve with no moving parts – to let cool air in and hot air out. The headphones feel light and comfortable, and unlike a lot of recent headphones, they favour form and function over style.

The company's crowdfunders have also had a say in all of its features. There's Bluetooth and every kind of cable, while the headphones come equipped with customisable touch-sensitive controls. There's no active noise-cancelling tech, but the isolation from the cups is good enough for most noisy situations other than a long flight. And there's possibly more to come. As Nuraphones get to test more and more sets of ears, they'll start to collect a bunch of data on our collective hearing. Who knows what they'll learn, but they might actually be able to tell you if they start to notice any problems or worrying degradation in your hearing.

VERDICT

The Nuraphones are a bold and original piece of tech that'll make you rethink what's possible. With these headphones on you feel like you're being bathed in sound. We spent our week with the device listening to old albums over and over again and showing all our friends just how impressive they were. They'll be sorely missed.

Ultimately, since the sound is tailor-made, it's difficult to say just how others will react to Nuraphones. But what I will say is that if you love music and consider yourself an audiophile, then you ought to find a way to try these brilliant headphones out for yourself. **9/10**



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XF18-135mmF3.5-5.6 R LM OIS WR	£95
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BBF57

MEDICINE GETS PERSONAL





Here's a staggering statistic: it is estimated that up to 75 per cent of cancer drugs do not work on the person they are prescribed for. This is because medicines are developed to work on 'the average person' when in fact all of us – and our diseases – are unique

WORDS: TOM IRELAND

ILLUSTRATION: TANG YAU HOONG

M

odern medicine, for all its wonders, has a rather large blind spot. Though scientific breakthroughs and new miracle treatments are announced on a seemingly daily basis, doctors know that even the most effective drugs in their arsenal won't work for large sections of the population.

For example, the drugs commonly prescribed to treat disorders like depression, asthma and diabetes are ineffective for around 30-40 per cent of people they are prescribed to. With hard to treat diseases like arthritis, Alzheimer's and cancer, the proportion of the population who see no benefit from a particular treatment rises to 50-75 per cent.

The problem stems from how treatments are developed. Traditionally, a drug is approved for use if it works for a good number of people with similar symptoms in a drug trial – and questions are not asked about those in the study who did not respond to the treatment. When the drug is then released and prescribed to the population *en masse*, unsurprisingly there are plenty of people – like those in the trial – who discover that the latest 'miracle cure' isn't all that miraculous for them.

This 'one size fits all' system of drug discovery – though it helped uncover the most important medicines of the 20th Century – is now increasingly seen as ineffective, outdated and dangerous. It means medicines are developed to work on 'the average person', when in fact all of us – even our diseases and our responses to drugs – are unique. Not only are many drugs ineffective for large subsections of the population, but they can also cause severe adverse reactions in others.

Thankfully, a completely new approach to medicine is gaining ground. As we learn more about how people differ genetically, medical professionals are tailoring healthcare advice and medical treatment to individuals, rather than populations.

THE PERSONAL TOUCH

Personalised medicine (sometimes known as 'precision medicine') uses a patient's genetic data, and other data about their health at the molecular level, to work out the best treatment for that individual person and others with a similar genetic profile.

We tend to think of our genes as determining things such as our height, eye-colour, or whether we have a genetic disorder. But the combination of genes

• we are born with affects our development and health in many subtle ways over the course of our lives. The likelihood of us getting certain diseases as we age, the way we metabolise food, and our reaction to certain drugs are all influenced by the genes we have.

Given what we now know about genes, taking this approach may seem somewhat obvious. But it has only been made possible in the last decade, thanks to the incredible progress that has been made in DNA sequencing technology.

When the human genome was first decoded in 2003, it took over a decade of international collaborative efforts and cost \$3bn. Just 15 years later, sequencing a person's genome takes hours rather than years, and can be done for under \$1,000. This means genetic information is more readily available to doctors and researchers developing treatments than ever before.

The area where the new personalised approach to medicine has had the greatest impact, so far, is in oncology, or cancer treatment. The treatment of lung cancer, especially, is seen as a great success story of precision medicine.

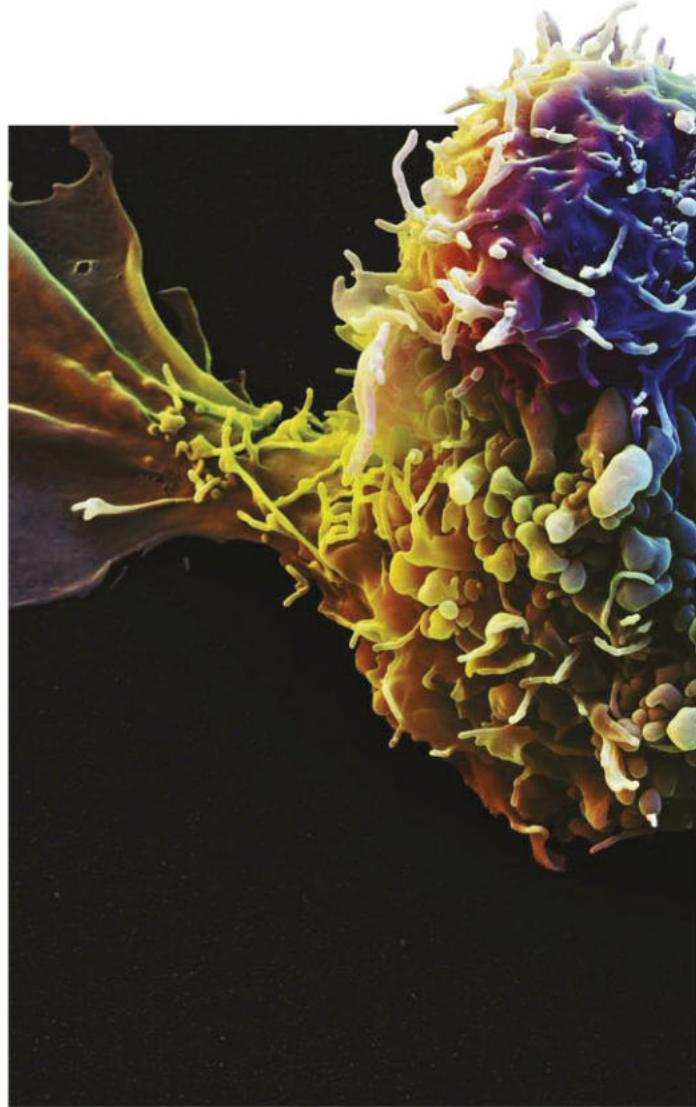
WAR ON CANCER

For years, doctors were puzzled as to why only around 10 per cent of lung cancer patients responded to a common cancer drug known as TKI (tyrosine kinase inhibitors) that halts a tumour's growth. In the late 2000s, when researchers were

"A GENETIC TEST CAN FLAG THE KEY GENES THAT MAKE PEOPLE HYPERSENSITIVE TO CERTAIN MEDICINES"

able to look at the DNA of patients' tumours, they found the drug actually only worked in people whose cancer cells had one particular mutation in a gene known as EGFR. The mutation causes cells to grow uncontrollably, and TKI blocks this effect, shrinking the tumour. But in patients whose tumours have different genetic origins, a course of treatment with TKI will result in a barrage of nasty side-effects with no chance of success.

Eventually, the different genes at the heart of different lung cancers were revealed, and the entire process for diagnosing lung cancer changed. Cancers are no longer simply classified by where they grow and what they look like under the microscope. Instead they are tested for gene



mutations, and treatment options are chosen accordingly. Even when tumours mutate during treatment and develop resistance to gene-specific drugs, doctors can track the genetic change and pick another target.

Even more sophisticated personalised cancer treatments are on the horizon, such as immunotherapy, which takes a patient's own immune cells and reprograms them to attack cancer cells. The immune cells, known as CAR T-cells, are extracted from the patient and genetically modified in the lab so they recognise the exact molecular markers growing on the patient's cancer cells, then injected back in the body to attack the tumour. The USA's Federal Drug Administration (FDA) approved a form of this treatment in August following impressive results in clinical trials.

Personalised medicine is also making an important contribution to the safety of drugs. Suffering a serious adverse reaction to a medicine may seem rare, but is, incredibly, the fourth leading cause of death in North America, and accounts for as many as 7 per cent of all hospital admissions. Again, the problem is caused by our tendency to try and treat large groups of very different people in the same way.



ABOVE: A cancer cell (yellow/green) being attacked by CAR T-cells that have been taken from a patient's immune system and modified

RIGHT: 23andMe was the first genetic testing kit that UK consumers could buy from a high-street pharmacy, to find out more about traits and ancestry



A simple genetic test can flag the key genes that make some people hypersensitive to certain medicines, or if someone metabolises drugs so quickly that they need a higher dose. This approach, known as pharmacogenomics, is still far from commonplace in hospitals and GP surgeries, but new software is in development that will help doctors make prescribing and dosage decisions based on a patient's specific genetic profile. We could one day even see pharmacists checking your genes in-store before handing over your medicines.

DATA-DRIVEN

Personalised medicine is not just about genetics. The medicine of the future will be driven by the generation and interpretation of many types of molecular-level data about individuals, captured with a level of precision never possible before.

"We now have technology that can tell us about your genome, your proteomic profile [protein levels], your metabolic profile and your individual microbiome, in detail, at a cost that is increasingly affordable," says Prof Pieter Cullis, a biochemist at the University of British Columbia and author of several books on personalised medicine.

"Gene analysis is informative, but your genes don't change over time and so they can't tell you if you actually have a particular disease or if your treatment is working. Proteins or metabolites in

Share and Compare

Share your reports with close family and friends to view your genetic similarities and differences. Trace the flow of traits, ancestry, and more from your grandparents to your children.



Close Family: Lactose Intolerance

ANCESTRY	Carrier Status (2)	Wellness (3)	Inheritance
Andrew: Likely intolerant	Carrier Status (2)	Lactose Intolerance	+
Lisa: Likely tolerant	Wellness (3)	Caffeine Consumption	-
Betty: Likely tolerant	Lactose Intolerance	Muscle Composition	
Add Grandparent			
Dave: Likely intolerant	Trait (22)		+
Carol: Likely tolerant	Ancestry (23)		+
You: Likely tolerant	Maternal Haplotype (7)		+
Dan: Likely intolerant	Paternal Haplotype (7)		+
John: Likely tolerant			

GENOME SEQUENCING

'Whole genome sequencing' involves reading the entire DNA sequence of a person or organism to produce a long string of the letters A, G, T and C – there are around three billion of these in the human genome. There are also vast sections of our genetic code which have no clear function, so sequencing is often used to reveal only the parts of the genome that contains genes (the 'exome'), or just key sections of variation or interest.

DNA must first be removed and purified from a sample of a person's cells. Chemicals can be used to 'amplify' even tiny amounts of DNA to give scientists more to work with.

To reveal the long sequence of chemical units that make up a person's genome, the purified and amplified DNA is chopped up into many thousands of pieces, which are then separated according to size using electric currents. These fragments form the signature 'bands' seen in an old-fashioned DNA sequence.

For many years, analysis of these bands was painstakingly done by eye, revealing one letter of the DNA sequence at a time. Hugely powerful machines, known as high-throughput sequencers, can now do the same thing in a fraction of the time.

► your blood give us a real-time picture of what your body is trending towards, or whether the drugs you have been given are doing what they are supposed to," he adds.

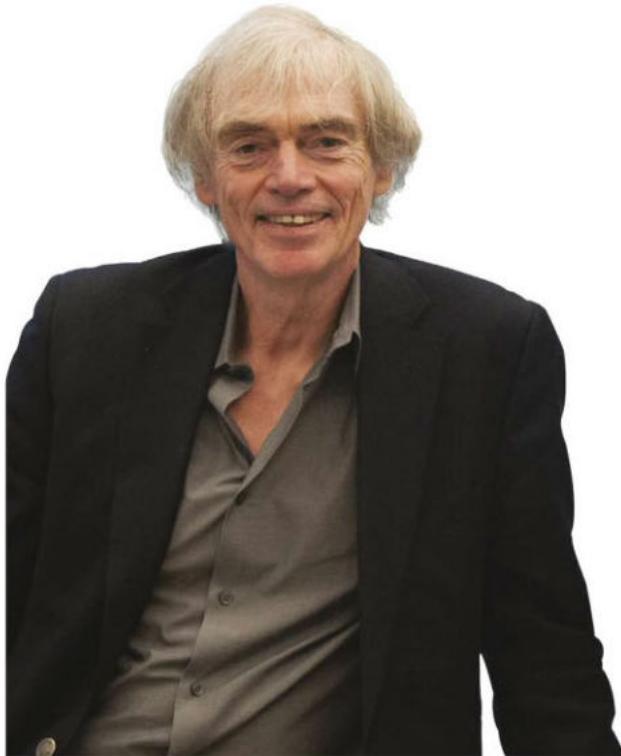
From a simple blood sample, scientists can detect the first chemical clues of a huge range of common diseases – known as 'biomarkers' – long before any physical symptoms become apparent. In pancreatic cancer, for example, many patients are only diagnosed when symptoms start to show and the disease is gravely advanced. But the cancer may in fact have been growing asymptotically for up to 15 years, releasing telltale biomarkers that could be detected with molecular tests.

According to Cullis, a combination of powerful computing, vast databases of genetic and biomedical data, and a greater number of skilled geneticists working in healthcare settings, has the power to truly revolutionise medicine. "We are going to move from sickness-based healthcare to

BELow: The human genome has been printed and bound. The 3.4 billion units of DNA that comprise the genome take up more than 100 books, each filled with 1,000 pages



PHOTOS: WENDY DOBBING, MOLECULARYOU.COM



“WE ARE GOING TO MOVE FROM SICKNESS-BASED HEALTHCARE TO PREVENTATIVE MEASURES, CATCHING THESE DISEASES BEFORE THEY HAPPEN OR WHILE THEY ARE STILL AT AN EARLY STAGE”

preventative measures,” he says, “catching these diseases before they happen or while they are still at an early stage.”

Dr Elaine Mardis, a professor of genomics and personalised medicine expert at the Nationwide Children’s Hospital in Ohio, calls this approach “precision prevention”.

“It’s about more regular monitoring and screening for people with high susceptibility to certain diseases. In its most extreme case, people have been found to have disorders that increase their DNA mutation rate or cause defective DNA repair mechanisms, making them likely to develop multiple cancers over their lifetime. They are then placed on a therapy that can hold off the first instance of cancer,” Mardis says.

Similar treatments known as ‘cancer vaccines’ – tailor-made treatments that help people develop ‘immunity’ to their particular cancer – are currently in development for a range of different diseases including kidney, oral and ovarian cancers. “That, to me, is precision oncology at its finest,” says Mardis.

BEYOND CANCER

Personalised medicine is starting to have an impact in many other areas of disease too. Last year, researchers from the Wellcome Trust Sanger Institute revealed that the most common and dangerous form of leukaemia is actually 11 distinct diseases that each respond very differently to treatment.

In HIV and hepatitis C patients, genomic data taken from both the patient and their viruses can help doctors decide on a drug combination that targets the specific strain of the disease and is less

ABOVE: Pieter Cullis believes personalised medicine will become a key way to prevent diseases like cancer

likely to cause side effects in that person. This is important because unpleasant side effects can cause some patients to stop taking their medicines. In Canada, this two-pronged approach reduced death rates from HIV by as much as 90 per cent.

And in Alzheimer’s – a disease that is notoriously difficult to treat – genetic analysis is revealing subtypes of the disease that are more likely to respond to certain treatments. Plus, doctors can initiate treatment earlier thanks to the subtle chemical clues that confirm the disease before symptoms are obvious.

But despite all this exciting research, and some remarkable successes, the fact remains that few patients entering the healthcare system in the UK will have access to the specialist biomolecular analysis required to personalise their treatment. Outside of oncology departments, large health systems like the NHS are not set up to gather and analyse biomolecular data for every patient yet. Personalised medicine is too often used as a last resort, or for the lucky few patients selected for clinical trials. The proportion of the population who have had their genome sequenced is tiny.

This is starting to change, however. In the UK, the 100,000 Genomes Project has begun sequencing genomes from around 70,000 people with cancer or a rare disease, plus their families, and last year the NHS published its Personalised Medicine Strategy to help drive the adoption of precision approaches in more areas of the health service.

In the US, the world’s largest precision medicine data drive was announced by Barack Obama in 2015. It aims to enrol and sequence genetic data from one million volunteers by 2020. According to Cullis, around 40 per cent of drugs approved in

• the US last year were 'personalised' in some way – meaning the treatment comes with a 'companion genetic test' to ensure it is precisely targeted. "In cancer the shift is already happening... companies will genome sequence a tumour and decide the best treatment for you," says Cullis.

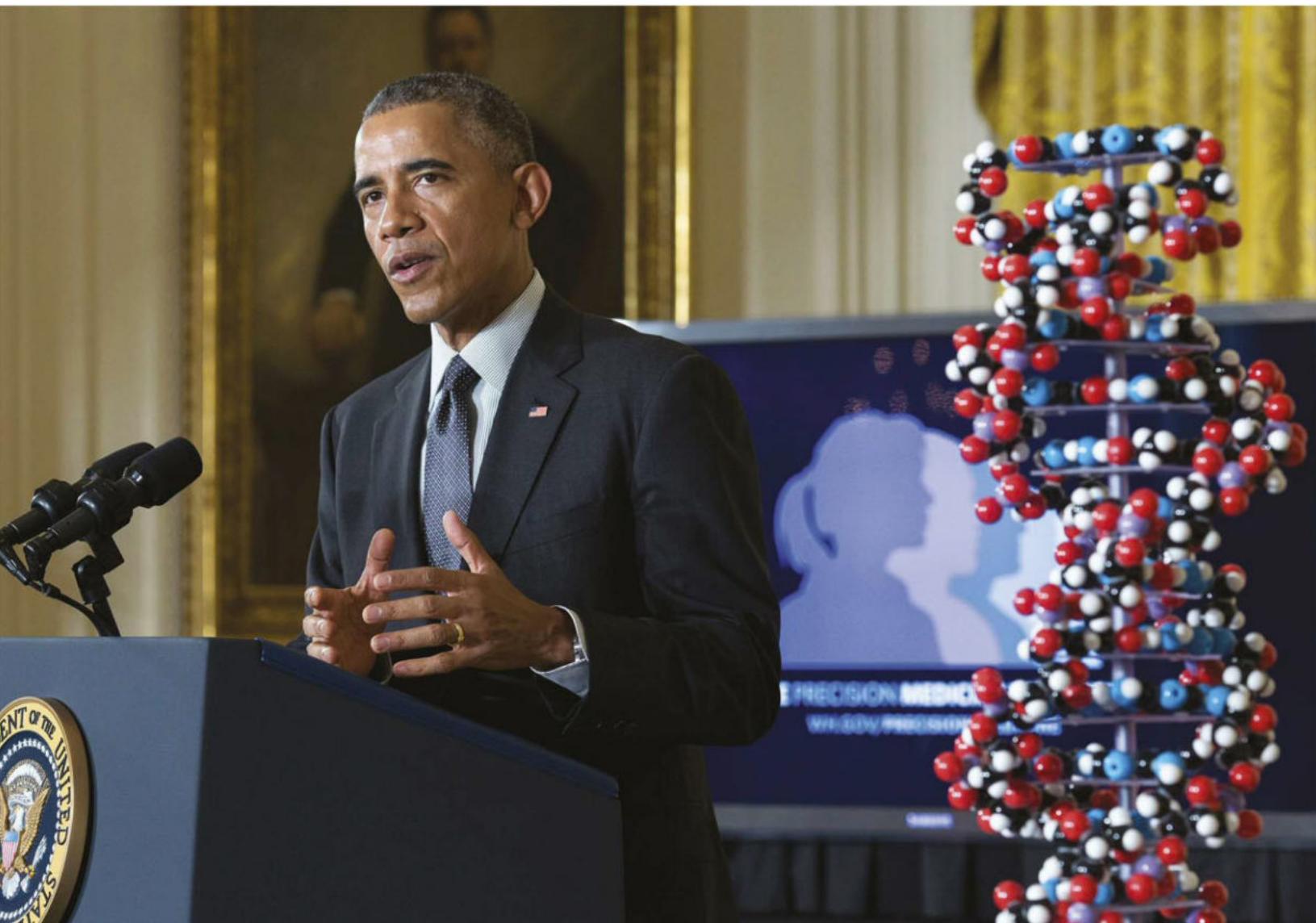
DOCTOR, DOCTOR

However, adopting personalised medicine across all areas of healthcare will require major reforms in how services are staffed and structured.

"A large emphasis of personalised medicine is on preventative medicine and treatment, and healthcare systems have never paid for that before," says Cullis. "It will be a huge shift and will require a lot of people who are not just doctors but trained in biomolecular analysis. The initial users of this will be people who can afford to pay for it themselves."

In the next few decades, Cullis foresees that visits to the doctor could be replaced by frequent updates from 'molecular counsellors', who track

"MOLECULAR ANALYSIS WILL BE SO DISRUPTIVE TO DOCTORS. IT WILL TAKE OVER THE DIAGNOSTIC AND PRESCRIPTION PROCESS. THE DOCTOR WILL BECOME YOUR HEALTH COACH, A PERSON WHOSE JOB IT IS TO KEEP YOU HEALTHY"





your health levels via regular analysis of the biomarkers in your blood, suggesting treatments that are right for your genes. This could be done virtually, with patients uploading their own blood samples to the internet for analysis, and consultation by Skype.

“Molecular analysis will be so disruptive to doctors,” says Cullis. “It will take over the diagnostic and prescription process. The doctor will become your health coach, a person whose job it is to keep you healthy and look out for signs that you need to perhaps go for a hike more often, or change your diet.”

So is it time to get your genome sequenced? Perhaps not just yet.

“Right now it’s about \$1,000 to have your genome sequenced, or about \$2,000 with the accompanying analysis,” says Cullis. “I had mine done and I didn’t find it all that useful. It told me I was likely to be susceptible to infections when I’m young – but I’m not young any more.”

However, as the infrastructure in healthcare systems becomes centred around bioinformatics and genetic medicine, it seems inevitable that the medicine of the future will be based around your genes.

“Genome sequencing is getting cheaper all the time,” says Cullis, “and you only need to do it once. When the systems are in place, it will provide important information about you every time you see a doctor, for the rest of your life.”

LEFT: As US president, Barack Obama launched the Precision Medicine Initiative to sequence the DNA of one million volunteers and track their health over many years

GPs OF THE FUTURE

A trip to see your GP could be very different if personalised medicine’s full potential can be realised in future. For a start, it may be your doctor that asks to see you...

- To keep track of your health in real time, you regularly upload samples of your blood or other fluids to the internet for remote analysis by experts.
- Assisted by data-crunching algorithms, analysts will alert your doctor at the first sign of the chemical signatures of disease or ill-health, long before any symptoms start to show.
- With your molecular data, genetic profile, family history and information about similar patients to hand, a doctor can prescribe a course of treatment suited to your unique circumstances and genes before you even feel ill.
- During treatment, the same molecular metrics of health and disease progression are monitored so that treatment is adjusted according to how you respond.
- If molecular analysis is advanced enough, much of the process of diagnosis and treatment decision could be conducted and communicated remotely via services such as Skype.

Tom Ireland is a science journalist and managing editor at the Royal Society of Biology.

DISCOVER MORE



Listen to an episode of *Inside Health* that discusses whether the NHS can deliver the benefits of personalised medicine at bbc.in/2wxyeA8



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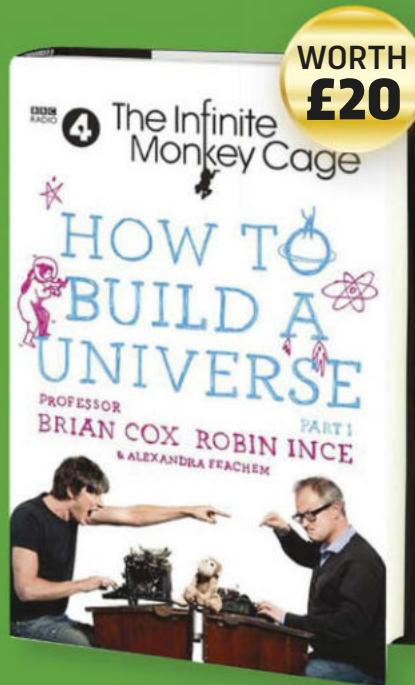
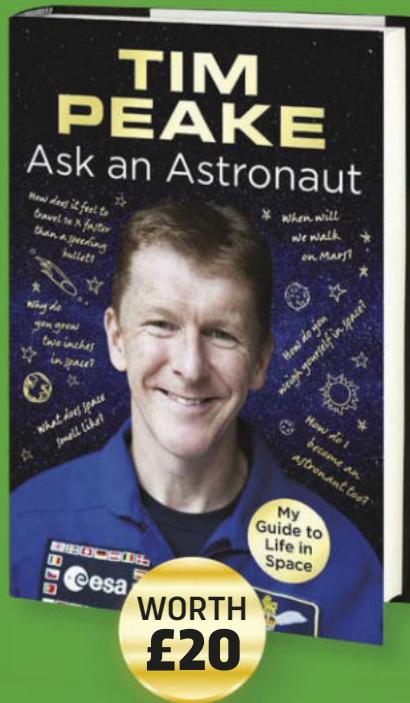
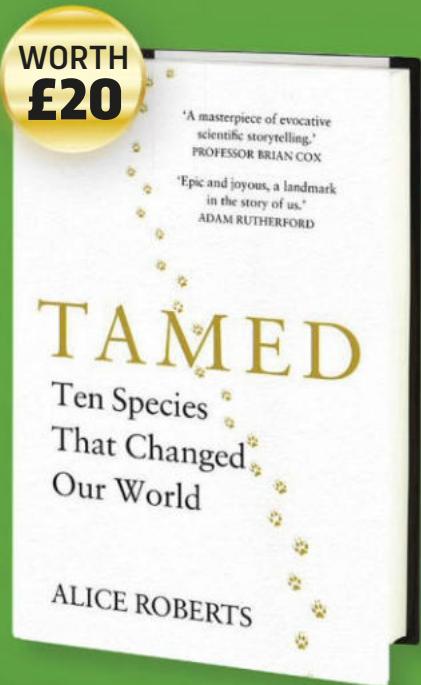
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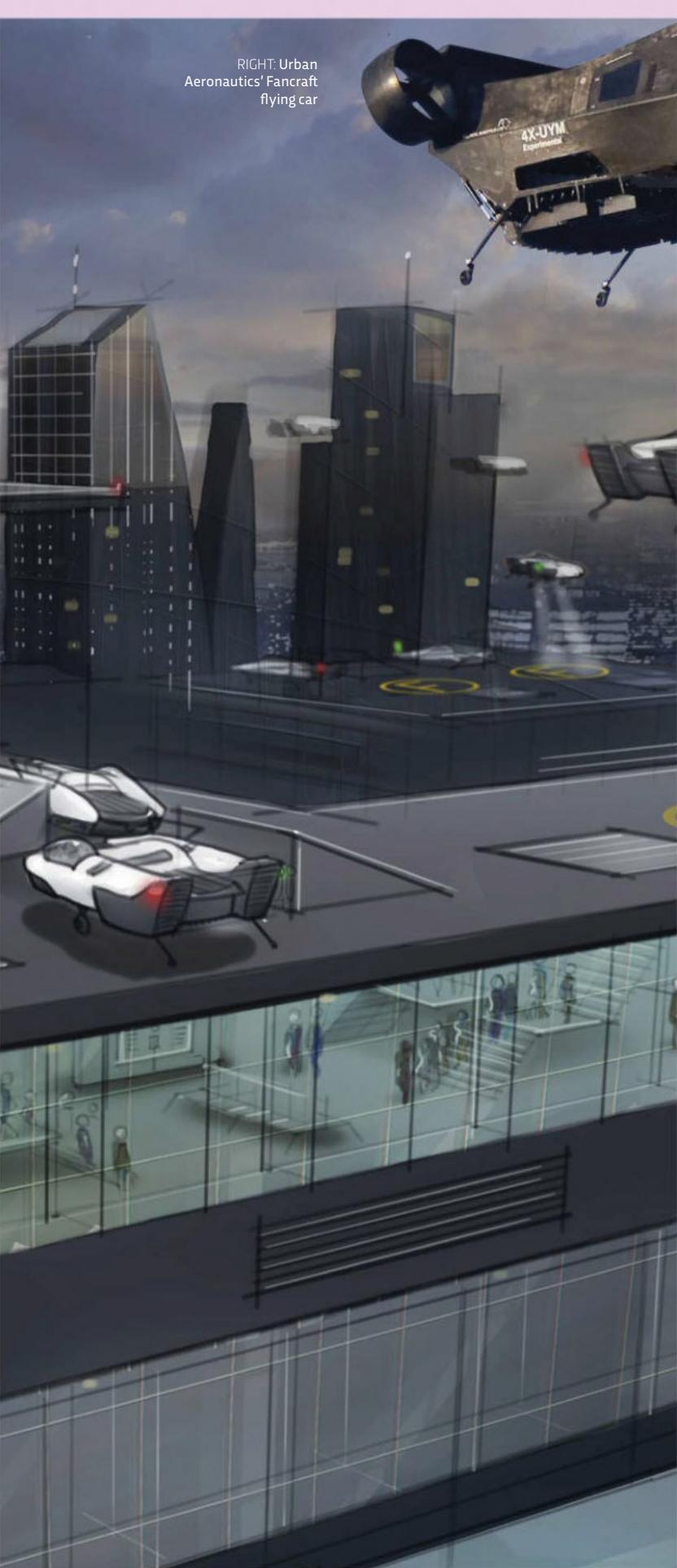


WHERE'S MY FLYING CAR?

BBC Focus turns 25 this month. Over the last three decades we've reported on some of the greatest advances in human history, but a few technologies never became a reality. Here's our rundown of the innovations we hope will become a part of our lives in the next 25 years...

WORDS: TIMANDRA HARKNESS

RIGHT: Urban Aeronautics' Fancraft flying car



FLYING CARS

5 YEARS AWAY

"The fabled flying car will finally become a reality as the cost of superconducting super-magnets drops" – BBC Focus, Summer 2011

You wait 50 years for a flying car, and then three come along at once.

First up is Vahana: an Airbus project to develop battery-powered, single-seater aircraft, designed to follow predetermined routes, only deviating to avoid collisions. Swivelling rotors on the wings will let it take off and land without a runway. Prototypes should be flying by the end of 2017.

Second, Dubai recently announced plans to test autonomous air taxis as a way to beat the UAE's notorious traffic jams. The Volocopter is an electric multi-copter with 18 rotors and a fully autonomous control system. It's essentially a scaled-up drone with two seats and up to 30 minutes of flying time.

But if you want something more like the airborne cars of 1950s sci-fi, try Urban Aeronautics' Fancraft. The Israel-based company wants to fulfil the dream of "an aircraft that looks like the classic vision of a flying car: doesn't have a wing, doesn't have an exposed rotor, and can fly precisely from point to point," says Janina Frankel-Yoeli, Urban Aeronautics' vice president of marketing.

Earlier flying cars needed runways to take off and land which was, as Frankel-Yoeli says, "not much better than owning a car and an aircraft." To go from point to point requires vertical take-off and landing, but for decades that could only be done by helicopters or larger aircraft. Urban Aeronautics' solution is to use light but powerful engines, lightweight composite materials, and automated flight controls. Their ducted fan design – propellers housed in aerodynamic tubes – is powerful but unstable, so the Fancraft would be challenging for a human to fly unaided. Instead, computer-aided control tech takes over the tiny, split-second adjustments required to keep the car stable at speeds of 160km/h (100mph) or more.

But don't put down a deposit yet. The main obstacle to a sky full of flying cars is regulation. Not only will every aircraft need to pass stringent safety tests, but a new system of air traffic control will be needed to cope with three-dimensional traffic jams above unwitting pedestrians. NASA is already working on that – tests have shown that multiple unmanned aerial vehicles (UAVs) can communicate with each other to avoid collisions. In the meantime, flying cars will mainly be reserved for emergency services and a few VIPs.

JETPACK

10 YEARS AWAY

"There's a new breed of solo flying machines ready to take off"
- BBC Focus, January 2014

Ready for your own Optionally Piloted Hovering Air Vehicle? New Zealand-based Martin Aircraft Company has your back. Okay, it's the size of a small car and uses fans rather than jets, but it has a roll cage, parachute and can stay in the air for half an hour. Sadly, there's still no firm on-sale date, so you have plenty of time to save up.





As part of a study at the University of Pittsburgh, Nathan Copeland, a quadriplegic, has had electrodes implanted in his brain. These communicate with a computer to give him a sense of touch via a robotic hand.

CYBORGS

20 YEARS AWAY

“After years of sci-fi dreaming, man is on the verge of becoming a cyber-being”
– BBC Focus, January 1997

In many ways, we are already cyborgs: contact lenses fix short sightedness; cochlear implants restore hearing; prosthetic limbs help athletes to match or even outstrip their natural-bodied rivals; and exoskeletons allow paraplegic patients to walk again.

The next challenge looks to be controlling artificial limbs and senses as instinctively as we do our bodies.

Brain-computer interfaces are the latest focus of Facebook, Elon Musk and US defence research funders DARPA, among others. Other laboratory studies have already allowed patients to control prosthetic limbs via electrodes implanted in the brain. University of Pittsburgh scientists even connected a paralysed man's sensory cortex to a robotic hand, allowing him to feel what the hand touched. Combining the strength, lightness and durability of today's prosthetic materials with similar brain control methods would

take us into superhuman, bionic territory.

Sensory augmentation is not far behind. Dr Robert Greenberg of US company Second Sight has developed implants that restore vision to blind patients. The company's Orion device is a retinal prosthetic that uses externally mounted video cameras to relay visual signals directly to the wearer's brain.

Over 250 patients tried Orion's predecessor, the Argus II, which translated camera output to optical nerves near the eye. Orion will bypass the damaged eye entirely, sending signals to the visual cortex at the rear of the skull.

“We are restoring relatively crude, but useful, vision to blind patients rather than improving normal sight,” says Greenberg. “Today's Argus II vision is like a blurry black-and-white television.” Orion should be an improvement, but “colour and higher resolution are in the future.”

While Greenberg is realistic about the current limitations, he's optimistic that we will eventually be able to restore sight to better-than-normal levels. “There is no physical reason why we can't create a high-resolution interface someday, but the engineering challenges are great,” he says. “I would guess we are at least 20 years away from superhuman vision.”



Film producer Mike Todd Jr (left) sits with Hans Laube, who is showing off his Smell-O-Vision machine. It was later used in Todd's film *The Scent Of A Mystery*.

FIVE THINGS THAT CAME AND WENT

Not every new technology has stood the test of time...

1 Smell-O-Vision

Inventor Hans Laube's Smell-O-Vision pumped perfume into 1960s cinema audiences, but his system never caught on. Then, in 2013, scientists in Tokyo came up with the 'smelling screen' for televisions. That hasn't really caught on either. Perhaps we just don't want to smell what we're watching, unless it's a baking show?

2 Pagers

Imagine being able to contact somebody at any time, no matter where they are! Back in the 20th Century this seemed an impossible dream, until the pager came along. By beeping or vibrating it would alert you that somebody had sent their number and wanted you to call back. On a landline. Later versions allowed text messages to be sent and received. By the mid-1990s, millions were in use, and then mobile phones appeared. Now only doctors use pagers.

3 Segway

Inventor Dean Kamen's hope that his transport device would change the world as much as the PC was foiled by the Segway's doubtful legal status: road vehicle or pavement plaything?

However, while the original is now largely used by security guards and tourists in flat cities, the company has found a new home in the powered scooter trend. Was this an idea before its time?

4 Zip drives

Anyone old enough to remember the floppy disk (yes, youngsters, the 'save' icon was once a physical object) may also remember wishing that they held more than 1.4MB of data. Then in the mid-1990s, the Zip drive came along, with its whopping 100MB per disk. Alas, it was soon superseded by the more flexible flash drive that pops in and out of a USB port.

5 3D televisions

In cinemas, 3D had a small renaissance when polarised lenses replaced the old red/green system. But most of us don't want to don 3D glasses in our living room. Is this because of a lack of 3D soap operas? Or having to sit in the same position every time? Or feeling stupid wearing high-tech specs with your slippers? Still, we're all going to be wearing VR goggles within the next couple of years, which is so 3D you leave your sofa, and your TV, behind.

HOLIDAYS IN SPACE

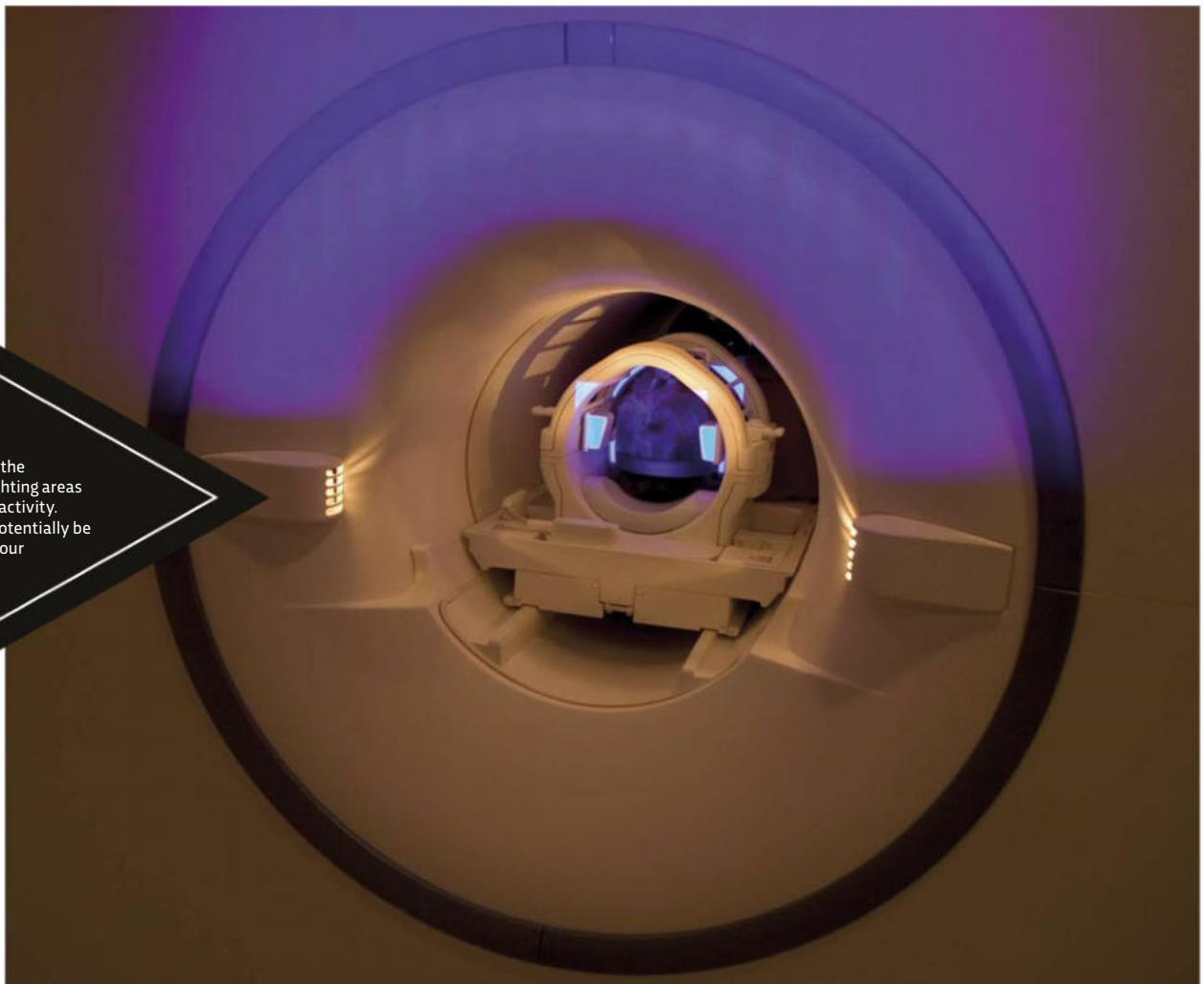
ALREADY HERE, IF YOU'RE A BILLIONAIRE

No, we still don't have hotels on the Moon or DisneyPlanet on Mars, but the first paying passengers have enjoyed unforgettable trips to the International Space Station. Now, private companies are racing to make space more accessible to non-millionaires. Virgin Galactic, SpaceX and even Manchester-based Starchaser Industries are testing the hardware that will safely get us there and home again.

MALE PILL

WITHIN 10 YEARS

Surprisingly, one of the most promising contraceptives for men is extra doses of testosterone, either on its own (doubling natural levels suppresses sperm production) or combined with other hormones. In clinical trials, some drugs have worked as well as the female pill. The main obstacles are delivery (many involve implants or regular injections) and side effects. Men might face mood swings, weight gain or acne as the price for not becoming fathers. Will they swallow it?



fMRI scanners measure bloodflow in the brain, highlighting areas of increased activity. They could potentially be used to read our minds in the future.

MIND-READING MACHINES

2-10 YEARS AWAY

“It seems like the world inside our heads may never be private again”
- BBC Focus, September 2008

Knowing what somebody is thinking would be a boon to law enforcement, suspicious partners, or Facebook advertisers. But attempts to match brain activity to specific thoughts have been crude and limited. But Prof Marcel Just, a psychologist at Carnegie Mellon University, has used functional magnetic resonance imaging (fMRI) to scan the brain and identify ideas as they form. His work goes beyond what a word looks or sounds like, to the building blocks of meaning.

fMRI is not usually time-specific. If someone's brain is being

scanned as they form a sentence, the successive ideas in the sentence will be blurred together in the scan image. “The novelty is our ability to separate out the individual concepts of the sentence,” says Just. This means training software to recognise the patterns of brain activity associated with different sentence elements.

In Just's study, participants lay inside fMRI scanners and read sentences such as ‘The angry lawyer left the office’, designed to include broad concepts like emotion and changes of location. Data from these scans was used to build models of how sentences with similar meanings, such as ‘The tired jury left the court’, would be represented in brain activity. These predictions were consistent between individuals, suggesting that our brains handle these concepts in a similar way.

“We all use the same set of

elements, even people who speak different languages,” says Just. “A model trained on data from English speakers can recognise thoughts from Mandarin speakers.”

There are limitations. While broad meanings can be reconstructed from the scans, similar concepts like tea/coffee, fish/duck may be harder to distinguish. Also, the subject has to be completely cooperative, which means it wouldn't work well as an interrogation technique. And for now it requires an unwieldy and expensive fMRI scanner.

But Just's team are working on an EEG (electroencephalography) version, which would only need a simple electrode cap to record electrical signals in different parts of the brain. He is optimistic about how soon a workable mind-reading device could be available. “Our grant ends in two years,” he says. “Ten years would be very slow and disappointing.”

ROBOT BUTLERS

25 YEARS AWAY

“Forget the dishes, leave the laundry and don’t even bother with the guttering. C-3PO is on his way” – BBC Focus, September 2008

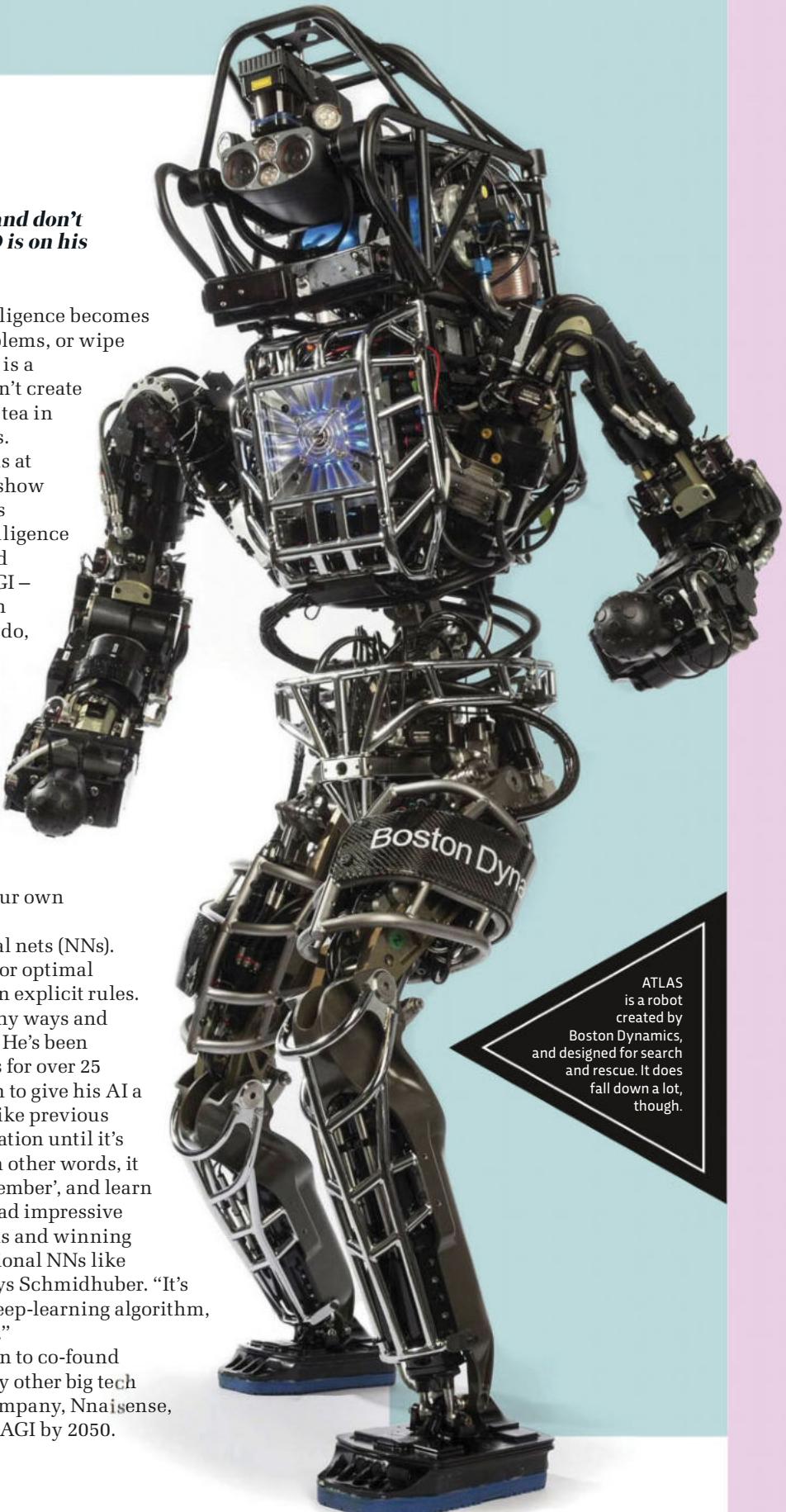
Do you believe that when artificial intelligence becomes smarter than us it will solve all our problems, or wipe out humanity altogether? Either way, AI is a game-changer. But currently, we still can’t create a robot that’s capable of making a cup of tea in the kitchen and then bringing it upstairs.

True, while AI is already better than us at playing *Go*, chess and even US TV quiz show *Jeopardy!*, Google’s DeepMind and IBM’s Watson are applying their machine intelligence to useful tasks like medical research and aviation safety. But will we ever have AGI – Artificial General Intelligence – that can match all the types of thinking humans do, using language in the same imprecise, contextual way, and adapting to the unpredictability of the physical world and emotional people?

One man who thinks we will is Prof Juergen Schmidhuber, head of Swiss research laboratory IDSIA. His Long Short-Term Memory (LSTM) machine-learning technique is used in Google Voice, Amazon’s Alexa and Facebook translation, and probably in your own smartphone, too.

LSTM is a development of earlier neural nets (NNs). NNs are programs that can find patterns or optimal solutions to problems without being given explicit rules. “NNs are computationally limited in many ways and insufficient for AGI,” says Schmidhuber. He’s been working on advanced deep-learning NNs for over 25 years, and developed the LSTM approach to give his AI a more human-like processing ability. Unlike previous versions, it’s able to hold relevant information until it’s needed, and to ‘forget’ less useful data. In other words, it can prioritise useful information to ‘remember’, and learn by trial and error from its mistakes. It’s had impressive results in sorting images, finding patterns and winning computer games. “LSTM relates to traditional NNs like computers relate to mere calculators,” says Schmidhuber. “It’s become the dominant general purpose deep-learning algorithm, and is now on three billion smartphones.”

Schmidhuber’s former students went on to co-found Google’s DeepMind, and to work for many other big tech companies. Now he’s started his own company, Nnaisense, and he’s hoping to achieve human-level AGI by 2050.



QUANTUM COMPUTER

AT LEAST 20 YEARS AWAY

As the laws of physics hamper the rush for smaller, cheaper and more powerful microchips, the elusive power of the qubit (quantum bit) grows more tantalising. Caltech scientists recently announced a breakthrough in using light to store data for quantum computing, capturing individual photons in memory modules the size of a red blood cell. It's another step towards a quantum chip, but a quantum computer fit for the mass market still looks decades away.

TIME MACHINE

NEVER. OR SURELY THEY WOULD HAVE COME BACK TO TELL US?

Breakthrough! A physicist at the University of British Columbia has calculated that it is theoretically possible to travel back in history, using the curvature of space-time. By recreating the time dilation that happens near a black hole, says Dr Ben Tippett, we could fold time into a circle. Unfortunately, to do that we'd need a new material called 'exotic matter' to bend space-time, and we haven't invented that yet. Back to the drawing board.

INVISIBILITY CLOAK

AT LEAST 10 YEARS AWAY

Invisibility is simple: it's just a matter of redirecting light so it passes right through, or around, the object you don't want to see. This year, a team from TU Wien achieved this by irradiating an object with a light pattern tailored to its internal structure, enabling them to guide the light through the object "as if the object was not there at all". So it's possible in the lab, but we're still a long way from hiding cars from traffic wardens on the street.



Holograms, like this giant interactive advert, feature prominently in this year's *Blade Runner 2049*.

3D HOLOGRAMS

25 YEARS AWAY

"The day may yet come when nothing will be guaranteed solid to the touch" – BBC Focus, January 1995

"Help me, Obi-Wan Kenobi, you're my only hope." That iconic hologram of Princess Leia from *Star Wars: Episode IV – A New Hope* looks fairly primitive, but we shouldn't judge too harshly. True workable holograms, that use lasers to trap 3D images in 2D planes, are trickier than they look. Yes, you can buy kits and make your own holograms at home, but these are fixed in time, limited in size, and have to be viewed in low light.

Today, our best way of creating a 'holographic' image is not a true hologram, but a form of either VR (virtual reality), AR (augmented reality) or MR (mixed reality) that's viewed through special headgear.

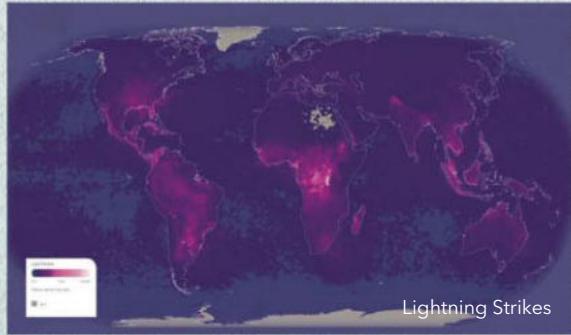
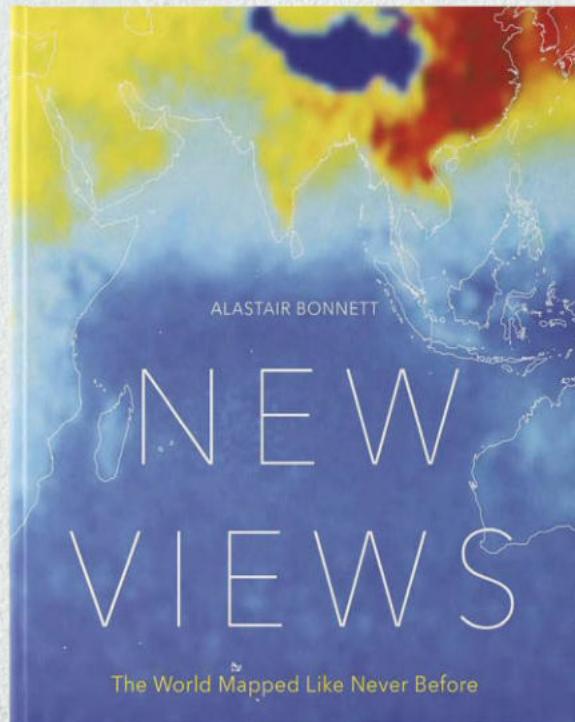
Microsoft's HoloLens, for example, projects the virtual objects onto a glass visor, using an array of sensors to orient the image to your real position. Other companies are working on similar solutions, with the goal of integrating the 3D image into what's really there. You'll be able to point, draw and move the virtual images, just like Tom Cruise in *Minority Report*. You could even project yourself into an office thousands of miles away.

You're probably thinking, "Fine, I don't care if it's not a real hologram, if it lets me interact with absent friends and workmates, then I'm in!"

But if you're a hologram purist, don't despair just yet. Making a true hologram, like taking a photo, involves recording the light bouncing off an object so that an image of the object can be reconstructed. Holograms use laser beams, creating interference patterns to give the 3D effect, but this requires some expensive and elaborate technology. It's tricky to do, and still the results aren't great. But researchers at the Technical University of Munich, led by Dr Friedemann Reinhard, have found a way to overcome the hurdles. Instead of using lasers, the team created holograms using radio waves emitted by a standard Wi-Fi router. The images are blurry (so don't expect any mini Princess Leias anytime soon), but recognisably show the shape of the original object. And Reinhard points out that, since Wi-Fi signals can pass through walls, their technology could allow us to see inside closed rooms, with obvious implications for security and privacy. Maybe you'll finally find out what your teenager gets up to (if you're sure you want to know). 

Timandra Harkness is a writer, performer and presenter of *FutureProofing* – back on BBC Radio 4 in spring 2018. bbc.in/2ydz2LX

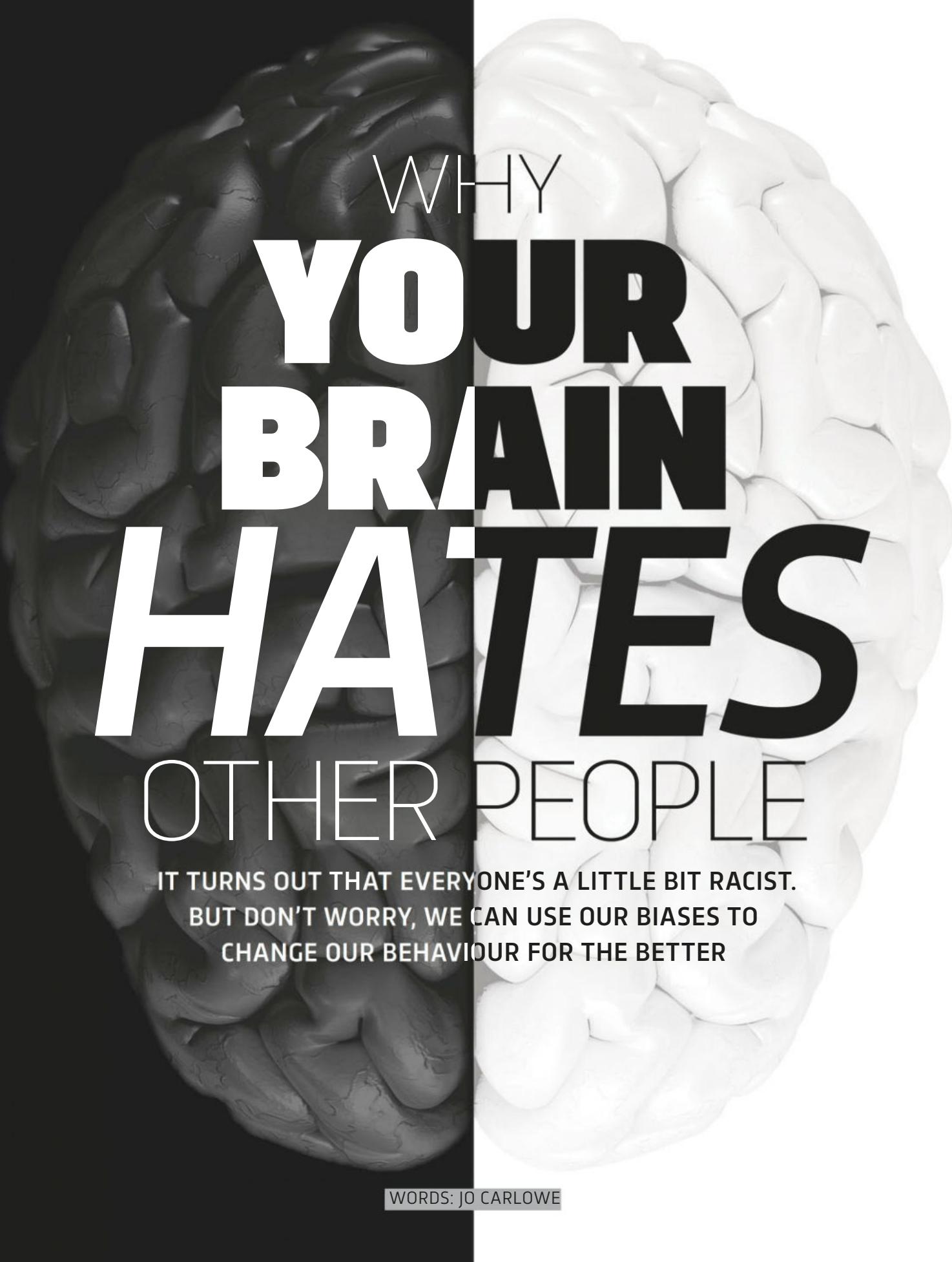
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WHY YOUR BRAIN HATES OTHER PEOPLE

IT TURNS OUT THAT EVERYONE'S A LITTLE BIT RACIST.
BUT DON'T WORRY, WE CAN USE OUR BIASES TO
CHANGE OUR BEHAVIOUR FOR THE BETTER

WORDS: JO CARLOWE

Chances are you're a bit racist. But don't blame yourself, blame your brain. We all have subconscious biases that are beyond our conscious control. Whenever we meet a new person our brains will quickly ascertain whether they are 'like us' or 'different', or 'for us' or 'against us', which will inform how we perceive them. Indeed, psychologists argue that our survival depends on this, as it was group affiliation that enabled us to harvest, hunt, build and thrive in the first place. But having an 'in crowd', means creating an 'out crowd', and therefore your brain does not view all people as equal.

At this point, you're probably shouting "Nonsense! I treat everyone the same!" Yet our biases are subtle, and are so deeply rooted in our unconscious that we don't know they exist. Often dubbed 'implicit bias', these attitudes insidiously influence how we think and behave. They can affect who we choose as friends and partners, and it can mean we ascribe personality traits to others based on little more than skin colour, sexual orientation or some other feature. This is different to what is seen in bigoted individuals, who knowingly and consciously discriminate based on factors of difference such as race or religion. Yet even though it is unconscious, implicit bias is still harmful as it can lead to discrimination and miscarriages of justice. So what can we do about it?

MIND MATTERS

According to Daniel Yudkin, a postdoctoral researcher at Oxford University and Yale, this 'us vs them' attitude is a by-

product of our evolutionary history, and is therefore not something we can easily help. In the workplace, it can mean unwittingly excluding candidates with ethnic-sounding names, unaware that unconsciously we hold an attitude that minorities are less qualified than others. In the boardroom it might mean men talking over women, because deep down (outside of our awareness) we think men have more important things to say.

On occasion, the implicit bias positively discriminates, although this is arguably not much better. We might attribute qualities to a particular group, due to nothing more than unconscious stereotyping. For example, a recruiter might gravitate towards Asian candidates for a job requiring maths, based on the unconscious stereotype that Asian people are maths wizards. If these truths seem uncomfortable, then rest assured that even country leaders are not immune. In early 1986, nearly one-quarter of Margaret Thatcher's Cabinet was Jewish. "I just wanted a Cabinet of clever, energetic people and frequently that turned out to be the same thing," she wrote in her memoirs. Anglo-Jewish journalist, the late Chaim Berman, thought that Thatcher had "a mystical faith in Jewish abilities".

Psychologists say we can't help but carve the world into 'us' and 'them'. "Group membership became an important manner in which people organised their social lives, but also their entire perception of reality," says Yudkin. According to research, this ingrained human need to belong can alter our behaviour. For example, in a small 2013 study at the University of Queensland, scientists randomly assigned people to red or blue teams and asked them to judge hand speed in a task. ☀



ABOVE: At one point, Margaret Thatcher's Cabinet was one-quarter Jewish, with members including Nigel Lawson (right). Some have suggested she had a positive bias towards Jews, believing them to be hard-working and clever



Two men sit outside a ticket office for 'non-whites' in Johannesburg during apartheid in 1979



● The participants ranked members of their own group as faster than those of the 'out-group', even when the speeds were identical.

"BUT I'M NOT A RACIST..."

While white supremacists are knowingly racist, people who consider themselves to be liberal and open-minded may harbour biases unknown even to themselves. We know this because in 1998 psychologists launched the Implicit Association Test (IAT), which uses pictorial and word association to explore hidden attitudes. Although 75 per cent of white test-takers reported no preference between blacks and whites, their IAT results suggested otherwise, with between 70 and 75 per cent showing implicit race bias.

Unsurprisingly, not everyone takes kindly to being told they harbour attitudes that they swear blind not to possess. Dr Kate Ratliff, executive director of Project Implicit (home of the Implicit Association Test), says people often respond by denigrating the test as unscientific.

But it's not just the IAT tests that brings hidden biases to the surface. Neuroimaging studies suggest our biases are 'etched' in our brains. MRI scan results show participants exhibit greater amygdala activity (the brain region associated with

"UNSURPRISINGLY, NOT EVERYONE TAKES KINDLY TO BEING TOLD THEY HARBOUR ATTITUDES THAT THEY SWEAR BLIND NOT TO POSSESS"

fear) when viewing faces that are racially different from their own. Likewise, participants show a larger startle response when presented with faces from different ethnicities.

Given the prevalence of this 'us vs them' attitude, one has to question how it all begins in the first place. The obvious view is that we learn it from our parents, but surprisingly, Dr Jan Van Bavel, associate professor of psychology and neural science at New York University, says this is not the whole picture. Yes, implicit bias is learned from sources such as parents, the media and the social norms of the day, but it also has a heritable component. "Twin studies find some people are not only more ethnocentric than others, but that this capacity for bias has strong genetic origins," Van Bavel explains. In other words, some people are perhaps inherently more prone to be biased than others. Nonetheless, all of us have it in us.



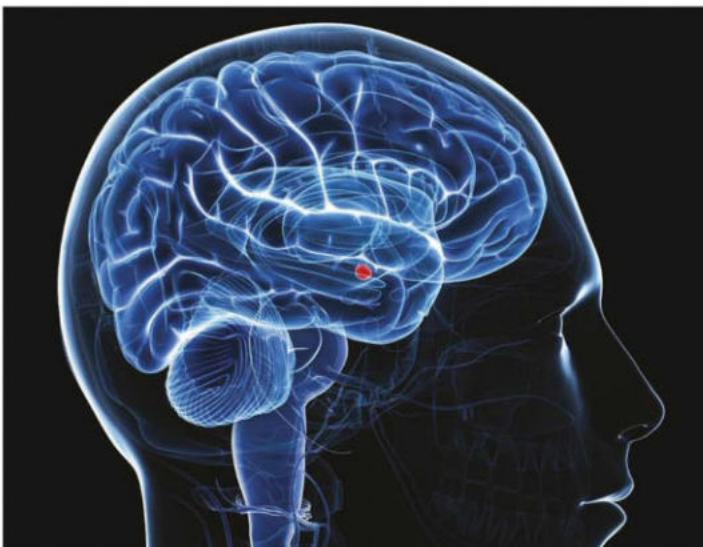
LEFT: Neo-Nazis, like these men who belong to the Nordic Resistance Movement, are consciously prejudiced, making judgments about people based on race. Activist Tess Asplund protests in front of them in Borlange, Sweden, in May 2016

So should we worry that implicit bias makes us latently racist or otherwise prejudiced? Most psychologists say not. While we should be aware of our implicit biases, we shouldn't beat ourselves up over them. They are, after all, a normal part of the human condition. "Our brains are wired to assess and categorise involuntarily based on past experiences, whether directly or indirectly," says Tuyen Fiack, the interim executive director of Silicon Valley FACES, a company that works with organisations to tackle the issue. Yet even she admits to being as prone as anyone else. "I might spark a conversation with a Vietnamese woman rather than a white male because my bias tells me I probably have more in common with the woman than the man because she looks like me. That's not 'bad' or 'good', it just is," she says. "Now if I force myself out of my comfort zone to speak to the man, I might learn we have things in common and form an unexpected friendship. That's why understanding our own implicit biases are so important. By understanding ourselves, we can better understand others, step outside our comfort zones and broaden our perspectives."

Fortunately, according to Yudkin, implicit bias has a low correlation with people's behaviour. "It is only when people are in a hurry, stressed, or distracted that implicit biases may be more likely to colour behaviour," he says. "It's not a bad thing for people to be biased – it's just a fact about the world. Once people admit this, it becomes easier to treat, talk about and undermine."

Nonetheless, our unconscious biases can have far-reaching implications, as was demonstrated in an experiment conducted by Van Bavel, Yudkin and colleagues. They tested how severely people would punish others for stealing. When perpetrators were perceived to support the same football team, or be of the same nationality as the punisher, they were treated more leniently than those from supposed rival teams or different countries. If we translate this attitude to the real world, it is easy to see how injustices arise. In the US, for example, despite white people and black people reporting similar levels of drug use, the imprisonment rate of black

BELOW: The almond-shaped amygdala (coloured red) in the brain controls a person's fear response



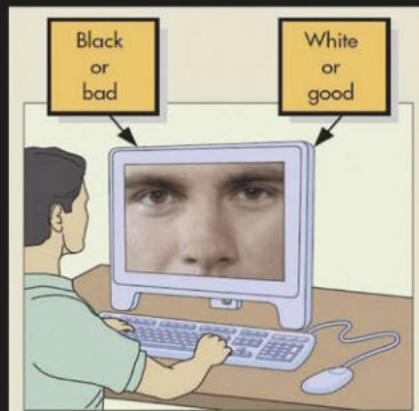
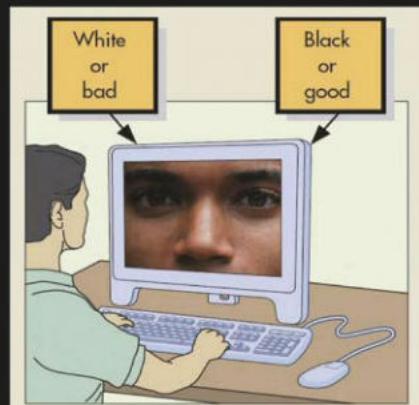
HOW BIASED ARE YOU?

THE IMPLICIT ASSOCIATION TEST (IAT) EXPLORES DEEP-SEATED ATTITUDES ROOTED IN OUR UNCONSCIOUS

Participants must speedily tap a computer key when they see faces or specific words and pair these with 'good' or 'bad' labels, selected by tapping a key with the other hand. The words and images are then switched.

For example, you may be asked to match black faces to words such as 'glorious' or 'beautiful', and white faces to words like 'hatred' or 'nasty'. The task is then switched with white faces matched to 'good' words and black to 'bad' ones. The results are compiled by comparing how quickly we correctly pair each picture group (say a set of black faces) to each label group (say a set of 'good' words). The longer the time it takes to accept a pairing, the greater our bias. So, if for example a person has quicker response times pairing white faces with 'good' words, than black ones, this suggests bias.

In the majority of cases, some implied bias is revealed. The test better predicts biases than surveys as it reveals preferences that we ourselves may be oblivious to. Try the test for yourself at: bit.ly/project_implicit_tests



● people for drug charges is almost six times that of whites. Meanwhile, in the business world, female-founded companies receive less venture capital than their male counterparts, suggesting an implicit bias against financially backing women.

BATTLING THE BIAS

Organisations are starting to fight back against implicit bias, and some have even set up training programmes to raise awareness. The National Initiative for Building Community Trust and Justice, for example, pilots interventions with US police departments. Here in the UK, professional service firm PwC runs Open Mind, which is a programme of psychological tests and awareness tools to help employees understand unconscious bias and its impact. Since the launch in 2011, the number of female and ethnic minority graduates that have been hired has increased.

Dominic Abrams, professor of social psychology at the University of Kent, believes the way we tackle implicit bias will follow a similar trajectory to the public health campaigns used to stamp out smoking, with education and legislation used to change norms. "Cigarette smokers used to be largely unaware of the harm that passive smoking caused to others, and most smokers certainly intended no harm. The point is

"PUTTING PEOPLE INTO A DIVERSE GROUP WITH A COMMON GOAL CAN REDUCE IMPLICIT BIAS"



ABOVE: Even though white and black people report similar levels of drug use in the US, nearly six times as many black people are imprisoned for the crime



ABOVE: People's biases can be overturned, if they believe they are working on the same team

that even if we can't stop people's craving for nicotine or stop them smoking directly, we can use our awareness of the effects to raise consciousness and do things to change the consequences for others," he says. "Likewise, with implicit bias, the biases might be present but we can limit the dangers they pose and change the factors that feed them."

According to Abrams, biases are more likely to become conscious or explicit once they have been challenged. History has demonstrated this. "There are countless examples – the suffrage movement, anti-slavery, challenges to traditional religious doctrine on homosexuality – that all involved overturning people's assumptions about the natural order of things," he says.

To help change our biases, we can use our 'groupish nature' to our advantage, by focusing not on changing our tendency towards bias, but on redirecting who we perceive as 'them' and who as 'us'. "Our research has consistently found that putting people into a diverse group with a common goal can reduce implicit bias. This happens in the real world all the time, like during times of war when diverse groups of people rally around their country," says Van Bavel.

Remember the amygdala study that demonstrated we show greater fear responses to images of people from other races? Neuroscientific research has revealed that the impact lessens when you put white and black people on the same team by having them wear the same colour shirts while cooperating on a task. "While the human tendency to derogate people perceived as 'other' is quite strong and pervasive, the capacity to change what counts as 'us' and 'them' is quite malleable," says Yudkin.

The ease with which one can manufacture an 'us' and 'them' paradigm might sound alarming, but on the flipside, it can be used to override pre-existing, automatic prejudices such as racial discrimination. As Van Bavel sums up: "Implicit bias emerges very swiftly once people are assigned to a group. Thankfully, we can use this same quirk of human nature that elicits implicit bias to help reduce it." ☀

Jo Carlowe is a freelance science writer and editor, specialising in psychology.

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SCI-FI AUTHOR ANDY WEIR
WEARS THE ICONIC SPACESUIT
FROM THE MARTIAN FILM

Is there life after Mars?

INTERVIEW BY: DANIEL BENNETT

***The Martian* author Andy Weir talks about his new book *Artemis*, how he built an entire lunar base in his head before he wrote it, and how hard it is to make a decent cuppa on the Moon...**

What is *Artemis* about?

Artemis takes place in a city on the Moon. The main character is a woman called Jazz, who's a small-time criminal that gets in way over her head.

Where did the idea come from?

I'd had the idea for quite a while. I actually built the whole setting – the lunar base – before I came up with the characters or story. One of the biggest challenges in sci-fi for me is lowering the stakes. People tend to expect planets to be cracking in half, but for me, the lower the stakes, the more realistic the setting. Metropolis in *Superman* doesn't feel like a real city to me, because every Tuesday there's a meteor coming to destroy it. With *Artemis*, I hope it feels like a real place. Whether the main character lives or dies, the city will go on.

Is it daunting try to follow up a book as successful as *The Martian*?

Inevitably, *Artemis* is just going to get compared to *The Martian*. I'm looking forward to my third book when people will hopefully stop doing that!

No one would ever accuse *The Martian* of being literature. There's no character depth, no one undergoes any sort of change, you don't even really know much about Mark Watney, who

you spend 350 pages with. You just know he really didn't want to die. For *Artemis*, I wanted more character depth. So Jazz is very flawed, she has lots of problems, she makes bad decisions. She does the wrong thing sometimes. That's very important for me: I make mistakes, so I find it hard to empathise with characters who always do the right thing.

Watney is the aspirational version of me. He's all the parts of my personality that I like, and none of the parts that I don't like. He doesn't have any of my flaws, neuroses or anxieties.

So what's Jazz like?

Jazz is a bit closer to the real me. I

“With *Artemis*, I hope it feels like a real place. Whether the main character lives or dies, the city will go on”

don't know if other people do this, but I come up with crime ideas all the time!

When I'm standing in line at the bank, I'll think, "I bet I could rob this bank." I mean, I wouldn't actually do it, but I bet I could. Jazz embodies those sinister thoughts you have in your head now and again.

So Jazz is a bit more the real me, and she has a lot of my flaws. Honestly, I'm really lazy. Most of my life I've been told that I'm not living up to my potential, so I injected a lot of my personal experience into Jazz.

Does that mean she's more likeable?

Probably less! People instantly empathised with Mark Watney. In a man versus nature story, nobody roots for nature, right? You automatically understand the motivations of a guy who doesn't want to die; as a writer, you don't need to explain them.

And Mark is this really likeable guy, whereas Jazz is a much more nuanced, more flawed character, and people don't immediately take to her. That's a real risk, because if you're not rooting for the main character, you're going to put the book down.

How did *The Martian* change your life?

My day-to-day life hasn't changed that much. I got a bunch of money, so ☺

• that's really cool. I bought a big house... and I bought a shergotite, which is a meteorite that originated on Mars. I have it on a little display on a pedestal. That rock used to be on Mars and now it's in my living room.

Where did you get it?

From a meteorite dealer. He's very reputable and provides you with the rock and the geological analysis that he's done on it to prove its origin. Every shergotite that's found is catalogued, so I know the ID of mine. There's a few hundred in the world in total.

We share a fear of flying... if someone slapped a ticket to space on your desk, would you take it?

Nope, absolutely not. I write about brave people, I'm not one of them! I wouldn't go into space or to Mars or the Moon or anything like that. But if you set up a situation where I can just go to sleep and wake up in space, and it's perfectly safe, then maybe...

So I worked it out for *Artemis*. For a rocket to take you into space you're pulling 3Gs on the ascent. So you have to be in the correct position, and you have to be trained to deal with it. But the book's set 70 years in the future, so I figure they'll have invented much safer anaesthetic. So they'd put you in a pod and just knock you out and wake you up aboard the space hotel. That way you don't have to deal with the horrifying reality of space flight.

Mark Watney had his love affair with potatoes... what do they eat on Artemis?

Well, they import a lot of food from Earth, so you can have anything. You can get a steak. But the cheapest food is gunk. It's basically chlorella algae, which is a real blue-green algae that you can grow in vats. The cool thing about chlorella is that it reproduces by doubling, so you can double your stock within a few days, and if you grow it right it'll give you everything you need, nutritionally.

It's clear in *The Martian*, and clearer still in *Artemis*, that you build worlds in your mind's eye for the characters to inhabit. What's that process like?

It's easy. I could spend all day doing it.



BEFORE BECOMING A FULL-TIME
WRITER, ANDY HAD A
BACKGROUND WORKING IN
SOFTWARE ENGINEERING

"I write about brave people, I'm not one of them! I wouldn't go into space or to Mars or the Moon or anything like that"

ANDY WEIR

The hard part is making characters and stories to happen in them. I like to set up the rules first and then play the game within them.

With *Artemis* I started off simply, with an economic reason for there to be a city on the Moon. It bothers me when I'm reading sci-fi and there's a Martian city with 10,000 people living there, but I'm left wondering *why*. Cities don't happen without an economic reason. For every city on Earth there's a reason it's there. So for *Artemis*, my explanation is that the price to get a craft to low Earth orbit is driven down by competition in the booster market by companies like SpaceX. Once you get out of Earth's gravity, visiting the Moon doesn't actually cost much more. I figured once we get to that point, a lunar city would develop naturally because of the tourism potential. Then I worked

forward. How do they build it? It's a tourist destination, so I went online and looked at some tourist spots in the Caribbean and so on. And that became the foundation of *Artemis*.

Next it was the fun stuff, the science. Thinking about how they might build a city on the Moon. You don't want to ship up hundreds of millions of tons of aluminium, so they'd make metal out of materials found on the Moon.

How does this turn into a book? Do you make notebooks? Do you have a corkboard with notes, pictures, pins and string?

I'd like one of those walls with paper pinned to it, but I've found Microsoft Word does that job fairly well! I have a document that has all of this stuff in it. I take down the salient notes and then there's just links pasted in. Like, "here's an article detailing every part of the FFC Cambridge process for



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A FILM VERSION HEADING TO
YOUR LOCAL CINEMA SOON

smelting anorthite [material found on the Moon] into aluminium."

Oh, and lots of spreadsheets!

In *Artemis*, Kenya has won the space race. How did they manage that?

The idea is that companies were competing to make ever cheaper boosters that got into low Earth orbit, and the minister of economics in Kenya realised they had a chance to build a space industry and pull themselves out of the third world. She realised they have two things to offer.

One: they're on the equator. It's cheaper to launch from the equator than from anywhere else, because Earth's rotation is fastest there. You get about 500m/s for free just because of Earth's rotation. That's not trivial: you need about 7,800m/s to leave, so you're getting 1 part in 16 for free.

So that means less fuel is needed...

Less fuel, less money. To take advantage of the Earth's rotation you launch eastward, which is why in the US our launch complex is Florida. It's as far south as we can get – as close as possible to the equator – and it also helps to launch over the ocean, in case the rocket fails.

In the book, the economics minister also realises that the best thing Kenya can do is offer policy. Other countries are mired with rules and regulations, so the Kenyan government decides to

create a set of laws that makes it so not only does the government get out of the way, but it actually encourages spaceflight with tax breaks and so on.

Artemis is what I think is a more realistic vision of the future. *The Martian* evoked feelings of the Apollo era, but it's not necessarily realistic.

How much of these imaginary worlds gets left behind, and doesn't actually end up being mentioned in the book?

Something like 98 per cent of it. I worked out all the details of how *Artemis* was built, starting from the first landing. There's all sorts of interesting ideas in there but they're not germane to the story.

In *The Martian*, you plotted the exact dates for the launch so the crew would spend Thanksgiving on Mars. Do you get a thrill out of that kind of detail?

I really do. One of the things I worked out – well, I found a paper on it – for *Artemis* was the Uphoff Crouch Lunar Cycler. It's an orbit that you can put something into – in this case, a space hotel – and it will just regularly come near the Earth and Moon, with no additional fuel necessary. In *Artemis*, you have to haul ass to catch up to the ship, but you don't need to accelerate this big, heavy human habitat every time. That took me a long time to understand, too. It's not just like it goes back and forth between Earth and the

Moon. The Moon's moving around Earth so it's this really bizarre orbit.

So how do you decide what stays in?

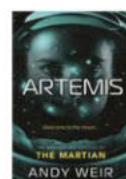
I think it's tiny details that really sell a setting. Something you'd never thought of that seems obvious in retrospect. For example, if you lived on the Moon you'd quickly find out that the boiling point of water is a lot lower – 61°C – because of the low atmospheric pressure. That means that your tea or coffee isn't going to taste very good.

As a Brit, that bit did make me think...

I actually get a lot of feedback on that one part of the book, which is funny. I've had people mail me and say you could make it in a pressure cooker to make proper tea. It would cool off back to a tepid 61°C once it came out into *Artemis*'s pressure, but at least it might have steeped properly.

I'm glad you've thought about this.

It's the tiny details. They sell it. 



Artemis is out now, published by Ebury and priced £12.99 for the hardback or £7.99 for the ebook.

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A very interesting simple and fun toy. When the lower portion of the glass sculpture is held, the liquid rushes into the upper section, and appears to boil furiously. Then hold the top section and liquid returns to the bottom.



Ferrofluid is a runny fluid that is magnetic. Hold a magnet to it and watch how it reacts. Some of the shapes you are can create are mesmerizing.



HELEN CZERSKI ON... ACOUSTICS IN THE WIND

"PADDLING INTO A HEADWIND MIGHT BE HARD, BUT COMMUNICATION IS NICE AND EASY!"

My Saturday mornings are often spent paddling along the Thames in a six-man outrigger canoe. These canoes are common in the Pacific but almost unheard of over here, and they're generally designed for exploring sunny coastlines rather than paddling past British pubs in the drizzle. Last Saturday was a grim, windy day. My friend Maria was two seats in front of me, making the call "hut", which was the signal for us all to change sides with our paddles, but I could barely hear her. At the turning point, she agreed to shout louder, but also said it would be easier for me to hear her coming home because I would be downwind of her instead of upwind. We turned into the wind and it was true – I could hear her much more easily when I was downwind. But why should the wind direction affect the sound you hear over such a short distance?

It's drummed into every experimental physicist that a change in a measurement might have two causes: the phenomenon itself or the detector you're using to measure it. Our ears are fabulous measurement instruments, but they have one major flaw from a physics point of view: they're attached to our heads. And in this case, your head is an obstacle to the wind.

Imagine standing with the wind coming from your left. At your left ear, where the air is being stopped by your head, there's a region of turbulence where the air is being mixed and mashed as it's caught between the oncoming flow and you. This layer of turbulence extends right around your head and as the air is shoved to and fro, your ears detect the associated chaotic pressure variations. You hear white noise: the roar of the wind. Any other sound has to compete with this roar, which is why it's always hard to hear on windy



days. In a stiff breeze, this sound itself can be as loud as 70 or 80 decibels.

Then on top of that there's another pattern. As the air approaches your head, it splits apart and flows around your left side relatively smoothly. But it doesn't just join together again on the other side and carry on. Instead, there will be a region of swirling air currents called eddies just to the right of your head, as the air jostles to fill the space after the obstacle. This extra turbulence can add another 10 decibels, so the wind is significantly louder at your downstream ear. But in the canoe, we all sit facing forward, so both ears should hear the same level of wind noise if the wind is in our faces or on our backs.

As I was paddling along thinking about all this, it occurred to me the difference might not lie with my detectors, but with the call coming my way. Maria was calling while facing away from me. So when I was upwind from her – the wind was at our back – she was shouting directly into the most complicated region of swirling eddies and maximum turbulence around her own head. As soon as the call left her mouth, it would be distorted slightly as it passed through the turbulence, making it harder for me to distinguish what was said. But when we turned around so that I was downwind, Maria was calling into relatively smooth air, and her call would have been clearer.

When we got back, the boathouse seemed peaceful

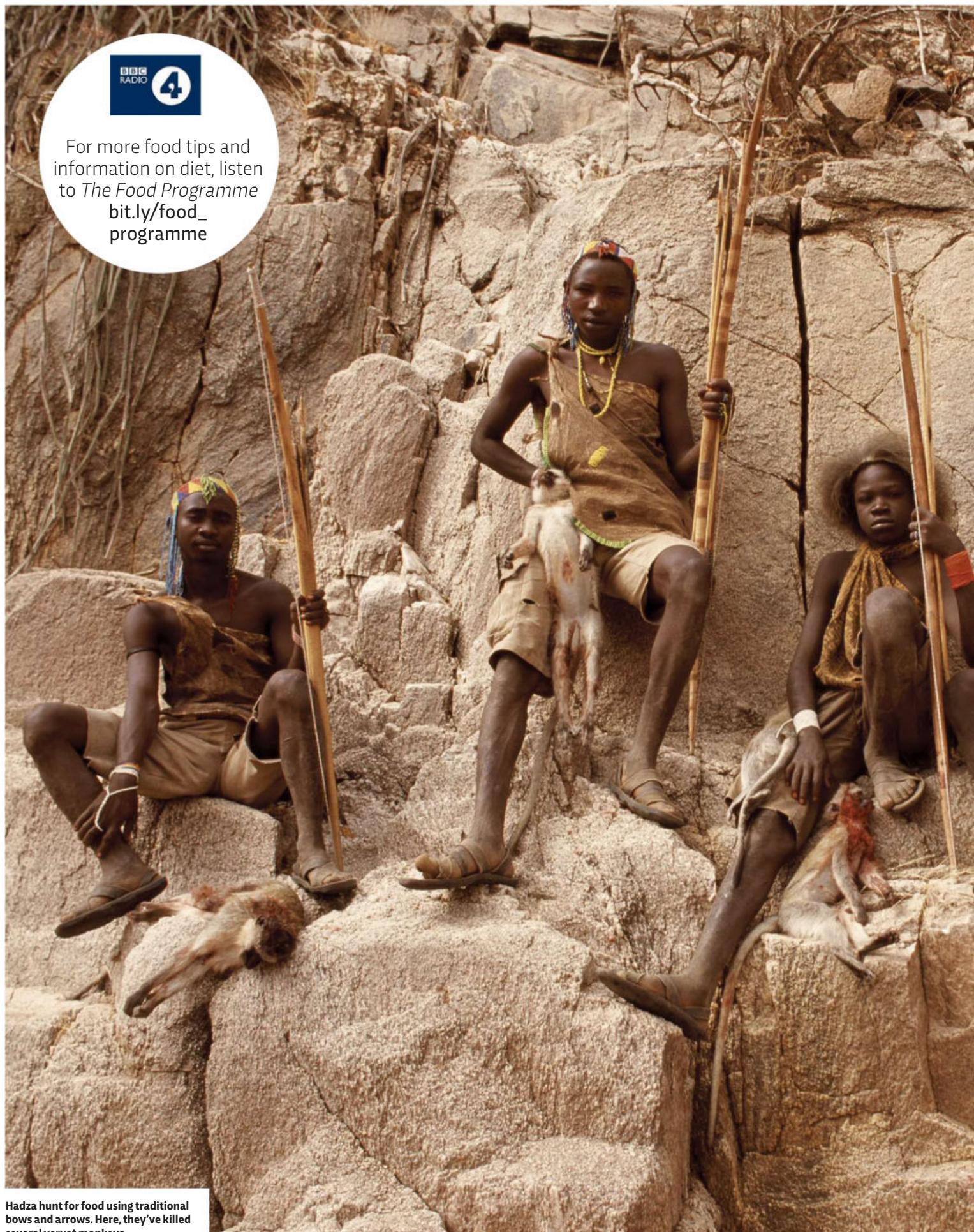
after the acoustic battering we'd had from the wind. But at least I've found a silver lining to console me during the hard work of paddling into a headwind – paddling might be hard, but communication is nice and easy! 

Dr Helen Czerski is a physicist and BBC presenter. Her new documentary on temperature will be shown in late 2017.

NEXT ISSUE: WHY ARE AEROSOL SPRAYS SO COLD?



For more food tips and information on diet, listen to *The Food Programme*
bit.ly/food_programme



Hadza hunt for food using traditional bows and arrows. Here, they've killed several vervet monkeys



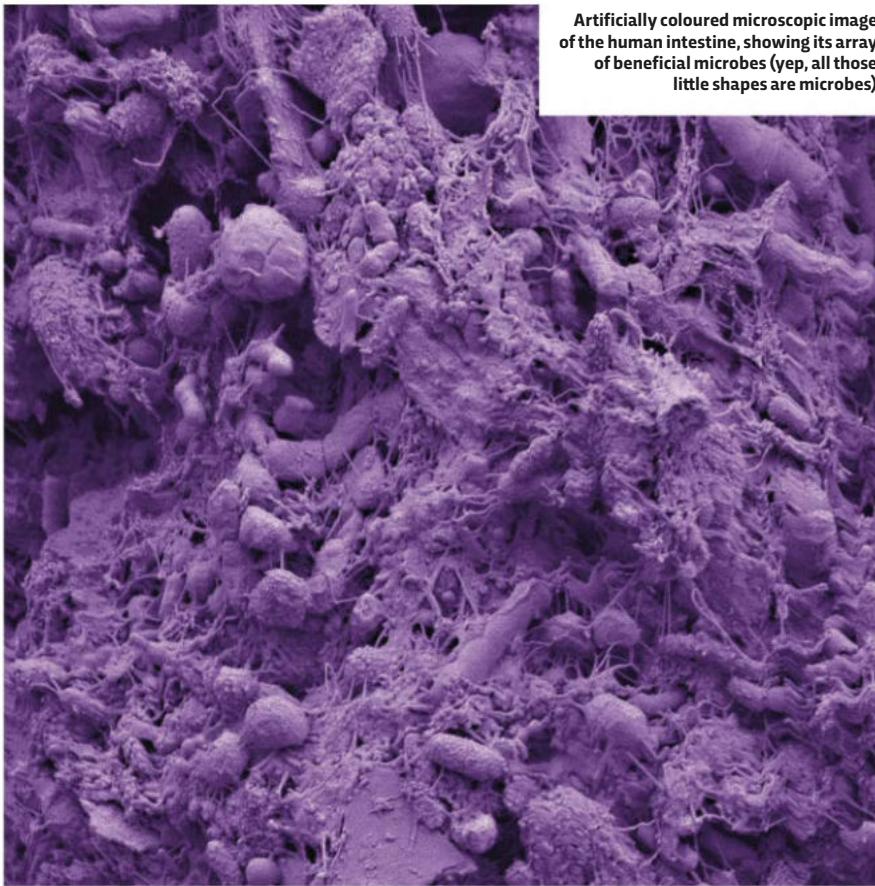
Fancy some porcupine, baobab and honey (with bee larvae) for dinner? Don't grimace: this hunter-gatherer menu might hold the secret to a healthier you. **Prof Tim Spector** reports on how he gave his microbes a treat by living with the Hadza people

REWILD YOUR DIET

Climbing to the top of a huge rock after a gruelling nine-hour drive in a 4x4 over bumpy tracks, we knew we had arrived. It had been an epic journey just to start this unorthodox camping trip. Here in Tanzania, a stone's throw from the famous Olduvai Gorge site of the earliest human remains, with the stunning plains of the Serengeti in the distance, we marvelled at the amazing sunset over Lake Eyasi.

I had not come here just to look at the scenery, though, breathtaking as it was. Strangely, I had signed up for a scientific experiment with my gut microbiome. This vast community of trillions of bacteria and fungi inhabit every nook and cranny of your gastrointestinal tract, and have a major influence on your metabolism, body weight, propensity to illness, immune system, appetite and mood. These microbes mostly live in your lower intestine (the colon) and outnumber all the other cells in your body put together. Conceptually, we should view them as a newly discovered organ, weighing slightly more than our brains and nearly as vital. There are some organs we can live without, including our spleen, gall bladder, tonsils and appendix, but we wouldn't survive long without our gut microbes. Intriguingly, no two microbiomes are the same – we are all unique. And more than ever, we're finding out just how important these microbes are.

According to research, the richer and more diverse the community of



Artificially coloured microscopic image of the human intestine, showing its array of beneficial microbes (yep, all those little shapes are microbes)

• microbes in your gut, the lower your risk of disease and allergies. This has been shown in animal tests and also in human studies comparing the microbes of people with and without particular diseases. Examples from recent work at King's College London include studies of diabetes, obesity, allergy and inflammatory diseases like colitis and arthritis. Meanwhile, there is mounting evidence that babies born via caesarean section miss out on some of the microbes they would obtain through a vaginal birth, which may make them more vulnerable to obesity, allergies and asthma.

We know that a good diet is key to maintaining diversity. While the definition of a good diet in the West is still controversial (such as the fat versus sugar debate), everyone agrees that large amounts of fruits and vegetables are key. As part of an experiment for my book *The Diet Myth*, I bravely volunteered my student son Tom to eat all his meals at McDonald's for 10 days so we could observe his microbes. He lost nearly 40 per cent of his gut diversity in that time and has only partly recovered – as he keeps reminding me. What we then wanted to find out is whether someone

with a healthy, stable microbiome could see the conditions inside their gut improve in just a few days. The chance to test this in an unusual way came when my colleague Jeff Leach invited me on a field trip to Tanzania, where he has been living and working among the Hadza, one of the last remaining hunter-gatherer groups in all of Africa. I had first met Jeff about three years ago. Jeff is a larger-than-life Texan and I was fascinated by his work and how he had tried to change his own microbes – even resorting (against all medical advice) to transplanting some poo from a healthy Hadza hunter into his own bottom using a turkey baster. I lacked Jeff's daredevil genes so didn't fancy repeating that experiment, but I was keen to do something just as exciting and hopefully less messy.

My own microbiome is pretty healthy nowadays – indeed, I came top among the first 100 samples we tested as part of our gut analysis project MapMyGut, although I have since been beaten by several others. It turns out the Hadza have a diversity that is one of the richest on the planet and about 40 per cent higher than the average American and about 30 per cent higher than the average Brit. Jeff and his team had previously worked out that the average Hadza person eats around 600 species of plants and animals in a year and has huge seasonal variation. They have virtually none of the common Western diseases such as

obesity, allergies, heart disease and cancer. In contrast, most Westerners have fewer than 50 species in their diet and are facing an epidemic of illness and obesity. From looking at our UK data, we can see a clear link between the amount and varieties of plants we eat and gut diversity.

“The Hadza have virtually none of the Western diseases such as obesity, allergy, heart disease and cancer”

HUNTING WITH THE HADZA

The plan was for me to spend an intensive three days living like a hunter-gatherer during my stay at Jeff's research camp. I was not allowed to wash or use alcohol swabs and I was expected to hunt and forage with the Hadza as much as possible, exposing myself to dirt, blood, and baboon and baby poo. The Hadza seek out and live with the same animals and plants that humans have hunted and gathered for millions of years. The interaction between the microbes in the Hadza's home and our own human cells is an evolutionary dance that has been played out here for millennia, shaping our immune system and making us who we are today.

After an interesting but restless first night's sleep, trying not to step on scorpions when going for a pee, I found a large pile of baobab pods had been collected for my breakfast. Baobab pods have a hard coconut-like shell that cracks easily to reveal a chalky flesh around large, fat-rich seeds. The baobab is the staple of the Hadza diet: it's packed with vitamins, contains fat in the seeds, and has large amounts of fibre. The Hadza mixed the chalky bits with water and whisked it vigorously for two to three minutes with a stick until it was a thick, milky porridge that was filtered – somewhat – into a mug. It was surprisingly pleasant and refreshing, and the vitamin C provided



A Hadza man with a variety of foods including baobab (large greyish pod) and kongorobi berries (orange), both of which are packed with fibre

an unexpected citrus tang. My next snacks were the wild berries on many of the trees surrounding the camp – the commonest were small, slightly sweet kongorobi berries. These have 20 times the fibre and polyphenols of cultivated berries, which are bred for looks and sweetness. This was powerful fuel for my microbiome.

After hanging out with the women and children doing some foraging, I had a late lunch of a few high-fibre tubers dug up with a sharp stick and tossed on the fire. These took a little effort to eat – mine was a bit too ‘al dente’ like tough, earthy celery. Babies were being breastfed and passed around for everyone to cuddle and play with. I never saw or heard any crying and they all looked healthy. They are weaned on baobab from six months and have 20 times the fibre intakes of Western kids. Some had large pot bellies – but rather than suggesting malnutrition, it showed their high fibre intakes and the resulting gas from the fermentation. I quickly learnt they were in no discomfort and were also amused by their noisy farts. After my baobab juice I soon joined in!

A few hours later we were asked to join a hunting party to track down porcupine, which is a rare delicacy. Even Jeff hadn’t tasted this creature in his four years of field work.

Two nocturnal porcupines had been tracked to their tunnel system in a termite mound. After several hours of digging and tunnelling by the slimmest of the Hadza, who occasionally shouted to his mates on the surface to dig more holes, the animals were spotted. Two porcupines were eventually cornered, speared and thrown to the surface. A fire was lit. The spines, skin and valuable organs were expertly dissected and the heart, lung and liver cooked and eaten straight away. The rest of the fatty carcass was taken back to camp for communal eating. It tasted much like suckling pig. We had a similar menu the next two days, with the main dishes including hyrax – a strange, furry, guinea pig-like animal and some birds I didn’t recognise caught by the older children.

I expected more berries for dessert – but we were in for a treat. With the help of some birds called honeyguides, a bee nest that was ripe for harvesting had been spotted 10m up a baobab tree. One of the Hadza used small wooden stakes to nimbly climb the tree and then confused the bees with smoke so they wouldn’t attack (much!). When the

HOW TO BOOST YOUR MICROBIOME

The microbes in your gut can help you to get thinner, be happier and live longer. Here's how you can give them a helping hand...



1. INCREASE YOUR FIBRE INTAKE. Aim for more than 40g per day, which is about double the current averages. Fibre intake has been shown to reduce heart disease and some cancers, as well as reduce weight gain.

2. EAT AS MANY TYPES OF FRUIT AND VEG AS POSSIBLE, AND TRY TO EAT SEASONALLY. The variety may be as important as the quantities, as the chemicals and types of fibre will vary, and each support different microbial species.

3. PICK HIGH-FIBRE VEGETABLES. Good examples are artichokes, leeks, onions and garlic, which all contain high levels of inulin (a prebiotic fibre). Some vegetables like lettuce have little fibre or nutrient value.

4. CHOOSE FOOD AND DRINKS WITH HIGH LEVELS OF POLYPHENOLS. Polyphenols are antioxidants that act as fuel for microbes. Examples are nuts, seeds, berries, olive oil, brassicas, coffee and tea – especially green tea.

5. AVOID SNACKING. Also, try to increase intervals between meals to give your microbes a rest. Occasionally skip meals or have an extended fast – this seems to reduce weight gain.

6. EAT PLENTY OF FERMENTED FOODS CONTAINING LIVE MICROBES. Good choices are unsweetened yoghurt; kefir, which is a sour milk drink with five times as many microbes as yoghurt; raw milk cheeses; sauerkraut; kimchi, a Korean dish made from garlic, cabbage and chilli; and soybean-based products such as soy sauce, tempeh and natto.

7. DRINK A BIT OF ALCOHOL. In small quantities, alcohol has been shown to increase your gut diversity, but large amounts are harmful to your microbes and your health.

8. STEER CLEAR OF ARTIFICIAL SWEETENERS LIKE ASPARTAME, SUCRALOSE AND SACCHARINE. These disrupt the metabolism of microbes and reduce gut diversity – in animal studies this has led to obesity and diabetes. Ditch the processed foods too, as these also upset microbes' metabolism.

9. SPEND MORE TIME IN THE COUNTRYSIDE. People living in rural areas have better microbes than city-dwellers. While you're at it, dust off your trowel: gardening and other outdoor activities are good for your microbiome.

10. STROKE ANIMALS. Studies have shown that people living with dogs have more microbial diversity.

11. AVOID ANTIBIOTICS AND NON-ESSENTIAL MEDICINES. Antibiotics destroy good and bad microbes, and it can take weeks to recover, so don't take them unless you need them. Their use is also associated with obesity and allergies in animals. Even common medications like paracetamol and antacids can interfere with microbes.

12. DON'T BE HYGIENE OBSESSED Fastidious washing and overuse of antibacterial sprays may not be good for your gut.

13. SPEND TIME CLOSE TO A LEAN PERSON. Studies in mice have shown that leanness may be contagious. Microbes from a lean animal can reverse obesity in a fat one, but strangely, obesity microbes are harder to transmit than lean ones.

14. AVOID FOOD AND VITAMIN SUPPLEMENTS. Only a tiny proportion of supplements have been shown to be beneficial. Instead, focus on eating a diverse range of real food to get all your nutrients.

“My gut microbial diversity and number of species increased by 20 per cent”

reassuring, were it not for the leftover entrails that would soon attract hyenas. I only had my poo-testing kit as a weapon. Luckily the Hadza are the best trackers in the world and on noticing I wasn't with them – to my immense relief – they rapidly found me. It felt like an eternity.

Twenty-four hours we were back in London with my cherished poo samples, which we sent to the lab for testing. The results showed clear differences between my starting sample and after three days of my forager diet. The good news was my gut microbial diversity and number of species increased by a stunning 20 per cent, and contained higher levels of many beneficial bacteria that we know can fight against obesity and inflammation. The bad news was, after a few days of my usual food and environment, my gut microbes had virtually returned to where they were before the trip. There were exceptions, though, and I have managed to retain a few African microbes that seem to be enjoying their new home and diet.

Within five years, I predict testing our microbes will be routine, as we personalise our diets to suit our own microbial species and to help reduce diseases. Until then, I believe everyone should make the effort to improve their gut health and microbe diversity by rewilding their diet and lifestyle (for tips, see opposite page). Understanding the intimate relationship between our food, our environment and our microbes should encourage us to be more adventurous and branch out from our usual dull cuisine. Every now and then I would highly recommend reconnecting with nature and our ancestral past to give our microbes a treat. 

Prof Tim Spector is professor of genetic epidemiology at King's College London, and author of *The Diet Myth: The Real Science Behind What We Eat* (£8.99, Orion). He tweets from @timspector

DISCOVER MORE



Listen to two episodes of *The Food Programme* with Tim Spector discussing our gut microbiome: bit.ly/gut_feeling_1 and bit.ly/gut_feeling_2



Honey straight from the comb is an important energy source for the Hadza, and many rank it as their favourite food

‘honey hunter’ descended, grinning, covered with a dozen bee stings, he brought a bucket full of the best golden orange honey I could ever imagine – full of fatty honeycomb, pollen and protein from the larvae. The combination of fat and sugars made our dessert the most energy-dense food found in nature and may have competed with fire in terms of its evolutionary importance a million or so years ago. Microbes from the bee gut are now found living happily inside the Hadza colons.

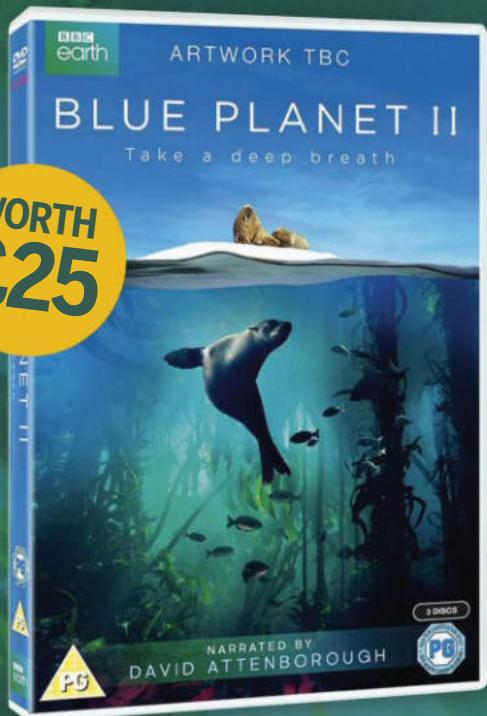
HOME TRUTHS

One lasting impression was how little time the Hadza spent getting food. It appeared as though it took just a few hours a day – as simple as going round a large supermarket. Wherever you walked there was food – above, on and below ground – with plenty of time for chatting, practising archery and socialising around the fire. I did briefly get a tiny glimpse of the other more dangerous side of their lives. While the porcupines were being dissected, I had a call of nature and went off to produce a stool sample for my experiment. When I returned 10 minutes later, clutching my test tubes, the hunting party had disappeared. When I realised they weren't playing games on me, I had a moment of feeling totally alone and useless with no clue which way to go. After some aimless wandering and shouting I returned to the old fire. This should have been

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Science Stories airs on
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As *Science Stories* returns, we uncover the story of Lise Meitner, the little-known Austrian physicist who kick-started the nuclear age

WORDS: PHILIP BALL

THE NUCLEAR PIONEER WHO ESCAPED THE NAZIS

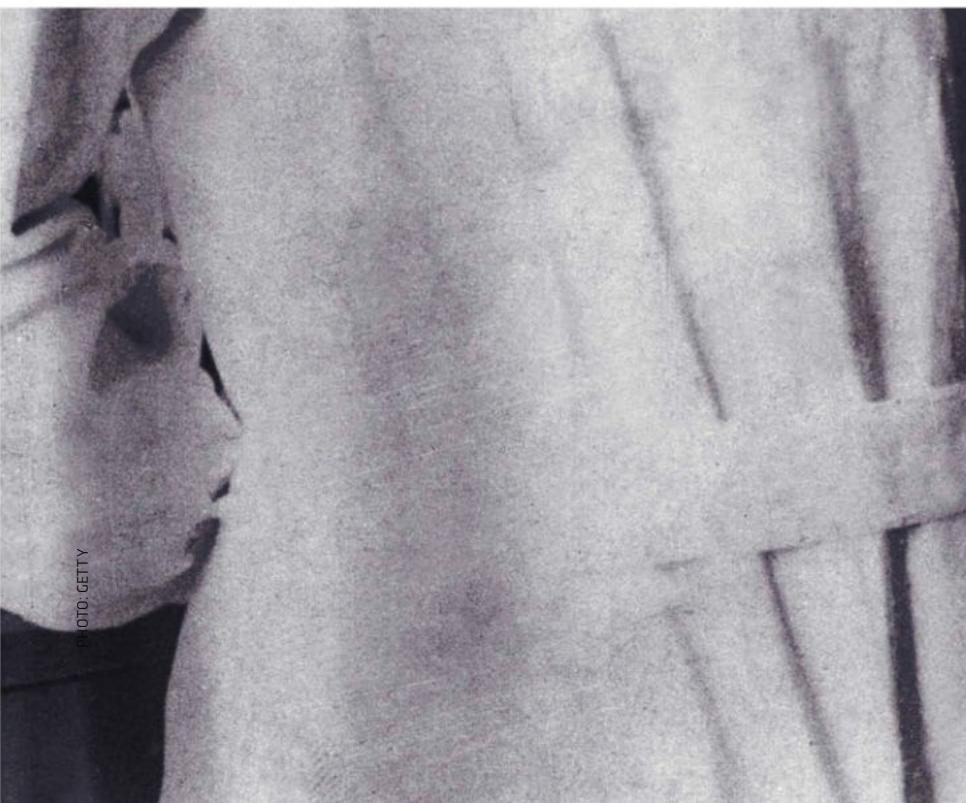
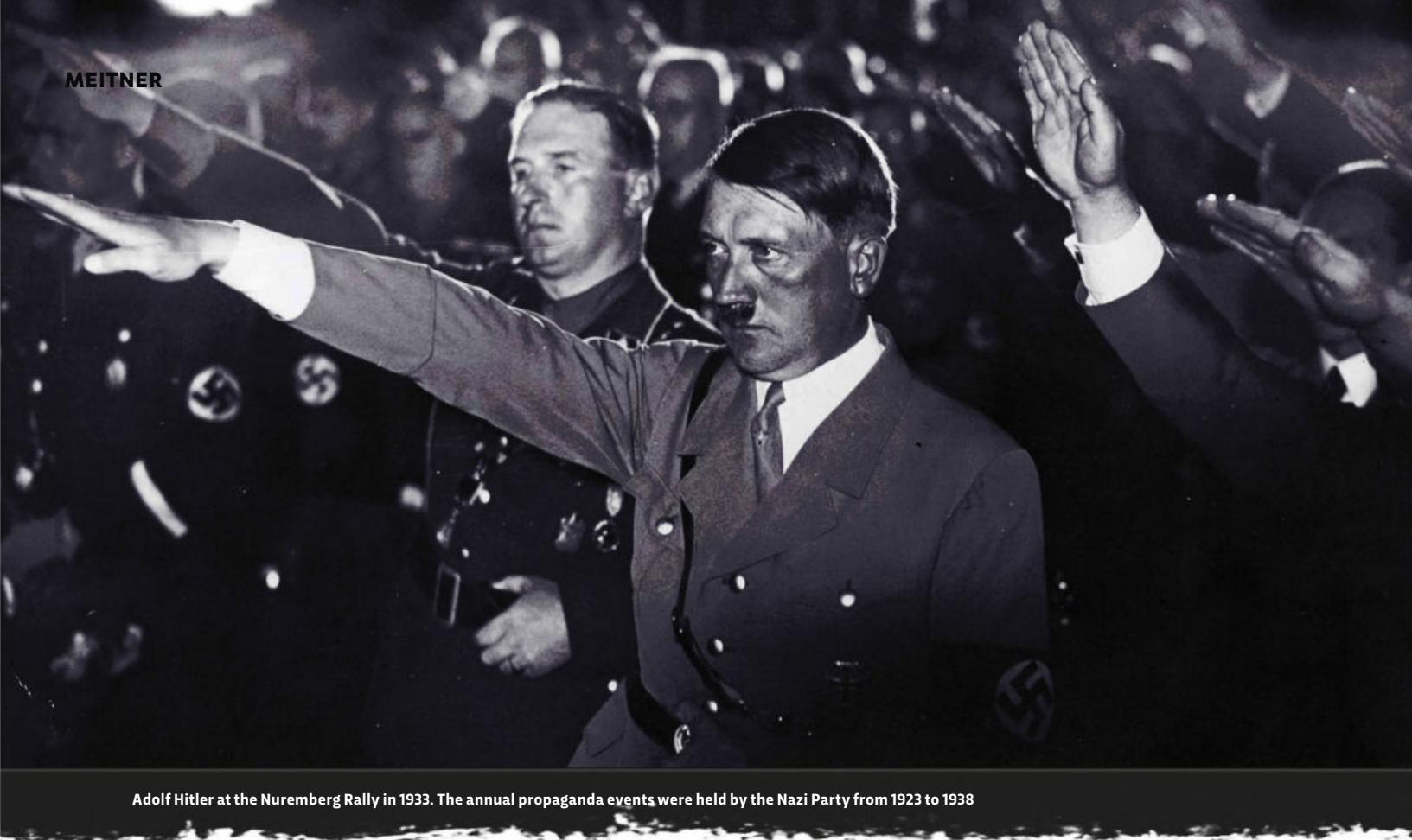


PHOTO: GETTY

One day in July 1938, a car pulls up at the train station in Berlin. A woman climbs out. She shows her travel documents to the armed guards in Nazi uniform. The woman is small and slight, and she seems nervous. On the train she greets a man and they travel together, heading for Groningen in the Netherlands. Are they lovers, perhaps?

No, this is not a tryst but a rescue mission. The woman is an Austrian named Lise Meitner, and is one of the most brilliant nuclear scientists working in Germany. She is of Jewish descent and is fleeing Adolf Hitler's regime when it is almost too late. The Nazi leaders have introduced a policy prohibiting all scientists from leaving Germany, and they have forbidden



Adolf Hitler at the Nuremberg Rally in 1933. The annual propaganda events were held by the Nazi Party from 1923 to 1938

“I got so frightened, my heart almost stopped beating. I knew that the Nazis had just declared open season on Jews, that the hunt was on”

Meitner from gaining the documents that would offer her freedom to travel. At the Dutch border, a Nazi military patrol makes its way through the carriages of the train, checking documents. Meitner's travelling companion, a Danish chemist named Dirk Coster, has negotiated permission from the Dutch authorities for her to enter the country. But all she has as identification is her Austrian passport – and it is obsolete. “I got so frightened, my heart almost stopped beating,” Meitner later recalled. “I knew that the Nazis had just declared open season on Jews, that the hunt was on. For 10 minutes I sat there and waited, 10 minutes that seemed like so many hours. Then one of the Nazi officials returned and handed me back the passport without a word.”

Minutes later, she was safely across the Dutch border. Once they arrived in

on a tour of the US when the election result was announced, never returned. But few would have been as valuable to Germany as Meitner.

A few months after her dramatic escape from Nazi Germany, Meitner was living in Sweden. She was told about the latest results that Hahn had obtained in his work on the radioactive decay of uranium. And she realised what Hahn did not: that uranium was undergoing nuclear fission, splitting in half and releasing some of its tremendous store of nuclear energy.

Seven years later, on 6 August 1945, that same process of nuclear fission in uranium was triggered inside Little Boy, the bomb that was dropped over the Japanese city of Hiroshima. The rest, you might say, is history – except that it is a history still all too present today, when the threat of nuclear conflict lies once again over the world. It was Meitner's insight that launched the nuclear age.

GLOWING CAREER

Meitner's career launched in 1901, when she decided to start studying physics at the University of Vienna. After achieving a doctorate, she arrived in Berlin in 1907 to take her studies further, but at the time Prussia (an historic German state, with Berlin as its capital) still did not admit women to its universities. That changed the following year, but attitudes did not. Hahn first met Meitner that autumn and they decided to work together. But women were not permitted inside Hahn's chemistry institute, allegedly because its director was convinced they would set their hair on fire. As a compromise, Meitner was given a room in the basement, but forbidden to come upstairs, even to talk to Hahn.

In 1912, Hahn and Meitner moved to the Kaiser Wilhelm Institute for Chemistry

Groningen, Coster sent a coded telegram back to Meitner's former scientific collaborator in Berlin, chemist Otto Hahn, to say that the ‘baby’ had arrived.

When Hitler came to power a few years earlier in 1933, his anti-Semitic policies lost German science many great researchers. Most famously, Albert Einstein, who was

(KWIC) to study radioactivity. This was the early 20th Century, and radioactivity was an exciting field for scientists because it offered clues about what atoms were made from. Researchers established that atoms have an internal structure, consisting of a positively charged super-dense nucleus made up of protons and neutrons, surrounded by negatively charged particles called electrons.

Scientists had also discovered that nuclear decay, and nuclear reactions triggered by collisions of subatomic particles with atoms, could convert one chemical element into another. And they found a whole bunch of new elements: Meitner and Hahn discovered protactinium in 1917.

LIVING UNDER THE SWASTIKA

During her time at KWIC, Meitner's determination and sharp mind soon earned her respect. By the 1930s, she was considered one of Germany's foremost nuclear scientists. But then everything changed.

In January 1933, Adolf Hitler was appointed Chancellor, and he moved swiftly to transform Germany from a democracy to a dictatorship. In April that year, the Nazis expelled Jews from all places of power and influence, including academic jobs. Yet somehow, Meitner managed to retain an academic post for a further five years. She was dismissed from the University of Berlin, barred from speaking at scientific meetings, and all but erased from the official narrative of German nuclear physics during that time, so that her joint discoveries with Hahn were attributed to him alone. Nevertheless, she was able to stay in active research at KWIC. Hahn and Meitner, assisted by a young German chemist named Fritz Strassmann, began to gather evidence for new types of radioactive substances created from uranium, perhaps including some hitherto unknown elements.

But when Germany annexed Austria in the Anschluss of March 1938, being an Austrian Jew in Berlin was no longer merely anomalous but perilous. Jews in Vienna were turned out of their homes and brutally beaten; some were murdered. Nazi sympathisers in Berlin no longer bothered to moderate their language – her colleague Kurt

PHYSICS UNDER HITLER

Many of Lise Meitner's colleagues remained in Germany, but their reaction to living under the Third Reich covered the full spectrum, from staunch pacifist to affirmed Nazi



FRITZ STRASSMANN (1902-1980)

One of the few German physicists whose opposition to the Nazis looks genuinely heroic was Fritz Strassmann, who worked with Otto Hahn and Lise Meitner at the Kaiser Wilhelm Institute for Chemistry. Strassmann despised the Nazis and refused to join any Nazi organisations, becoming blacklisted from jobs, and ending up poor and malnourished. He considered himself lucky when Hahn and Meitner found him an assistantship for half-pay in 1935. During the war, he and his wife hid a Jewish friend in their flat.



MAX VON LAUE (1879-1960)

Today the scientific reputation of Max von Laue rests largely on his discovery of the diffraction of X-rays by crystals: the basis of X-ray crystallography. He was one of the few scientists working in Nazi Germany to retain the respect of the Allies. It was said that Laue took to going out in the streets of Berlin with a parcel under each arm, so that he was absolved of the obligation to greet others with the Nazi salute.



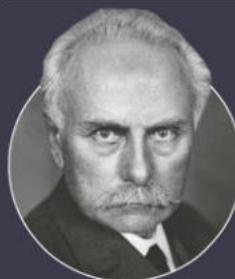
WERNER HEISENBERG (1901-1976)

Werner Heisenberg was perhaps the most brilliant theoretical physicist of his generation, helping to create a theory of quantum mechanics in the 1920s, for which he won a Nobel Prize. Yet he's one of the most divisive characters in German science. His craving for official approval led him to ingratiate himself to the Nazi authorities, even though he never sympathised with the regime. It has been suggested that Heisenberg sabotaged the German attempts to build an atom bomb by deliberately conducting false calculations, but there's no good evidence for this.



MAX PLANCK (1858-1947)

By the time Hitler came to power, Max Planck was an elder statesman of German science, having essentially begun the field of quantum physics in 1900. Although conservative by nature, he despised the Nazi regime, but never properly understood the threat it posed. The war crushed him: having lost his eldest son Karl in WWI, his second son Erwin was executed by the Nazis after being implicated in a plot to kill Hitler. His biographer John Heilbron describes him as a well-intentioned but tragic figure.



JOHANNES STARK (1874-1957)

Not many German physicists were out-and-out Nazis, but Johannes Stark was one of them. His experimental work on atomic physics won him a Nobel Prize in 1919, but he denounced Einstein's breakthroughs as "Jewish physics". When Hitler came to power, Stark tried to assert control over German physics, but he was too politically inept, managing only to alienate leading Nazis. Stark got off lightly in the post-war Nuremberg trials, having his initial punishment of six years' imprisonment reduced to a mere 1,000-mark fine.

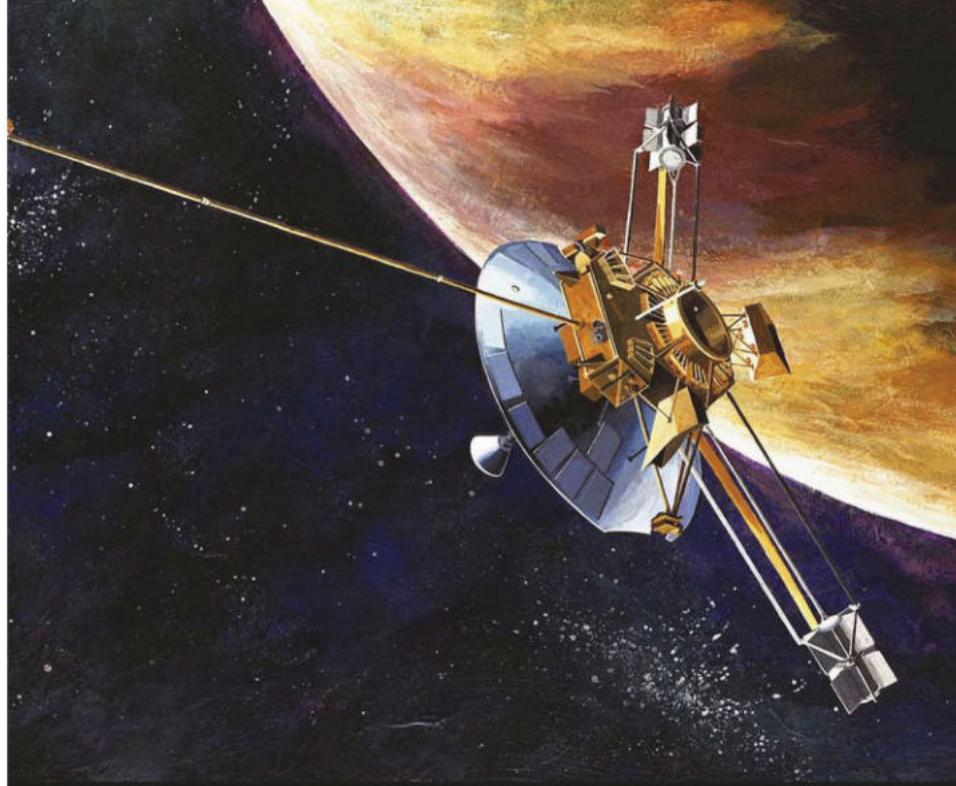
► Hess, who was an ardent Nazi, said of Meitner that “the Jewess endangers this institute.” Hahn, who had been Meitner’s closest colleague for 20 years, capitulated, telling her that she must leave the institute. “He has, in essence, thrown me out,” Meitner recorded bitterly in her diary.

It was time to leave, and fast. Dirk Coster at the University of Groningen in the Netherlands had been arranging emergency help for refugee scientists coming from Germany, and on 11 July 1938 he received official confirmation that Meitner would be admitted into the Netherlands. Two days later, he was accompanying Meitner on her escape from Berlin.

SPLITTING APART

Following Meitner’s escape from Germany, Hahn and Strassmann continued the uranium experiments. But without Meitner’s expertise they had difficulty interpreting what they saw. They found that uranium could be transformed by neutron bombardment into radioactive substances that seemed chemically similar to barium, a much lighter element. They wrote to Meitner, now in Stockholm, who replied that it did not seem credible. Radioactive transmutations were thought to happen only a little at a time: a radioactive decay would turn one element into another with very similar mass. Yet barium had barely half the mass of uranium.

That Christmas, while on holiday in a quiet Swedish village, Meitner discussed the peculiar results with her visiting nephew, the physicist Otto Frisch. He had also been exiled from Germany and was now working in Copenhagen. They came to a conclusion that contravened



Nuclear power isn't always bad: the batteries of the iconic *Voyager* space probes are nuclear-powered

all prevailing wisdom about nuclear transmutation. The uranium nuclei, they decided, had indeed been more or less split in half – raising the prospect of an enormous release of nuclear energy. Searching for a name for this process, Frisch recalled the division of living cells, and borrowed the biological term for it: uranium underwent nuclear fission.

By the end of April 1939, German physicists had told the Nazi government about the potential of nuclear fission to provide energy and explosives, and the authorities declared that such research should be kept secret. But word had already got out. In August, Einstein and other scientists wrote a letter to President Roosevelt warning of the feasibility of making an atomic bomb.

Later that year, the German physicist Werner Heisenberg wrote a report for Nazi officials on the possibility of liberating energy by controlled fission in a uranium-fuelled nuclear reactor – and perhaps also in a bomb. Heisenberg was put in charge of the research to harness this nuclear energy. But the German scientists, lacking the funding and hampered by Allied bombing raids, hadn’t progressed very far towards either a nuclear reactor or a bomb by the end of the war. They were as surprised as the rest of the world when they heard in August 1945 of the bombing of Hiroshima.

That capacity for destruction wasn’t the only feature of nuclear fission, though. In the midst of the war, scientists working under Italian physicist Enrico Fermi in Chicago figured out how to control fission so that it didn’t become a runaway process: uranium released its nuclear energy only gradually, generating heat that could be used to boil water and drive turbines for electrical power generation. Fermi’s success, ◉

TIMELINE: NUCLEAR FISSION

1896

While investigating X-rays, the French scientist Henri Becquerel observes radiation coming from uranium ore that turns photographic plates dark.

1898-1902

In Paris, Marie and Pierre Curie conclude that these unusual emissions are a new kind of energetic ‘ray’ – an effect they call ‘radioactivity’.

1904

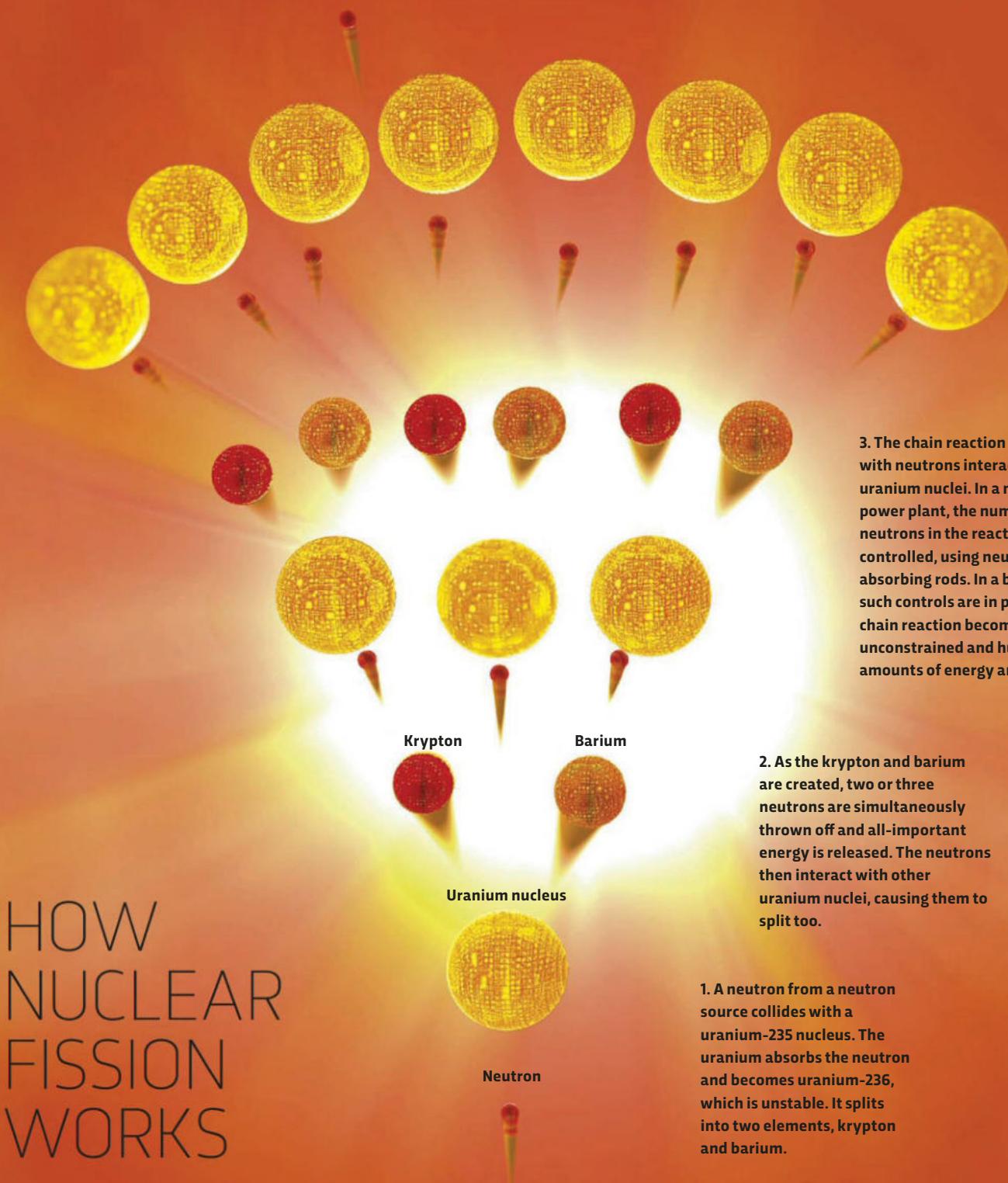
Working in Canada, Ernest Rutherford shows that some radioactive ‘rays’ are really particles: fragments, it turns out, of the decaying atomic nuclei.

1933

Hungarian scientist Leo Szilard realises that if the emissions from radioactively decaying atoms can trigger decay in other atoms, the result could be a chain reaction.

1938

Otto Hahn and Fritz Strassmann see fission of uranium, but cannot interpret their results. Lise Meitner and Otto Frisch conclude that the uranium atoms are splitting in half and releasing a great deal of energy.



HOW NUCLEAR FISSION WORKS

1939

Frédéric Joliot-Curie in Paris demonstrates that nuclear fission of uranium generates neutrons, creating the conditions for a chain reaction that might lead to sustained energy release, or an explosion.

1942

Enrico Fermi, an Italian scientist working in Chicago, creates the first 'nuclear pile' – a reactor that uses nuclear fission of uranium to generate heat energy.

1942-1945

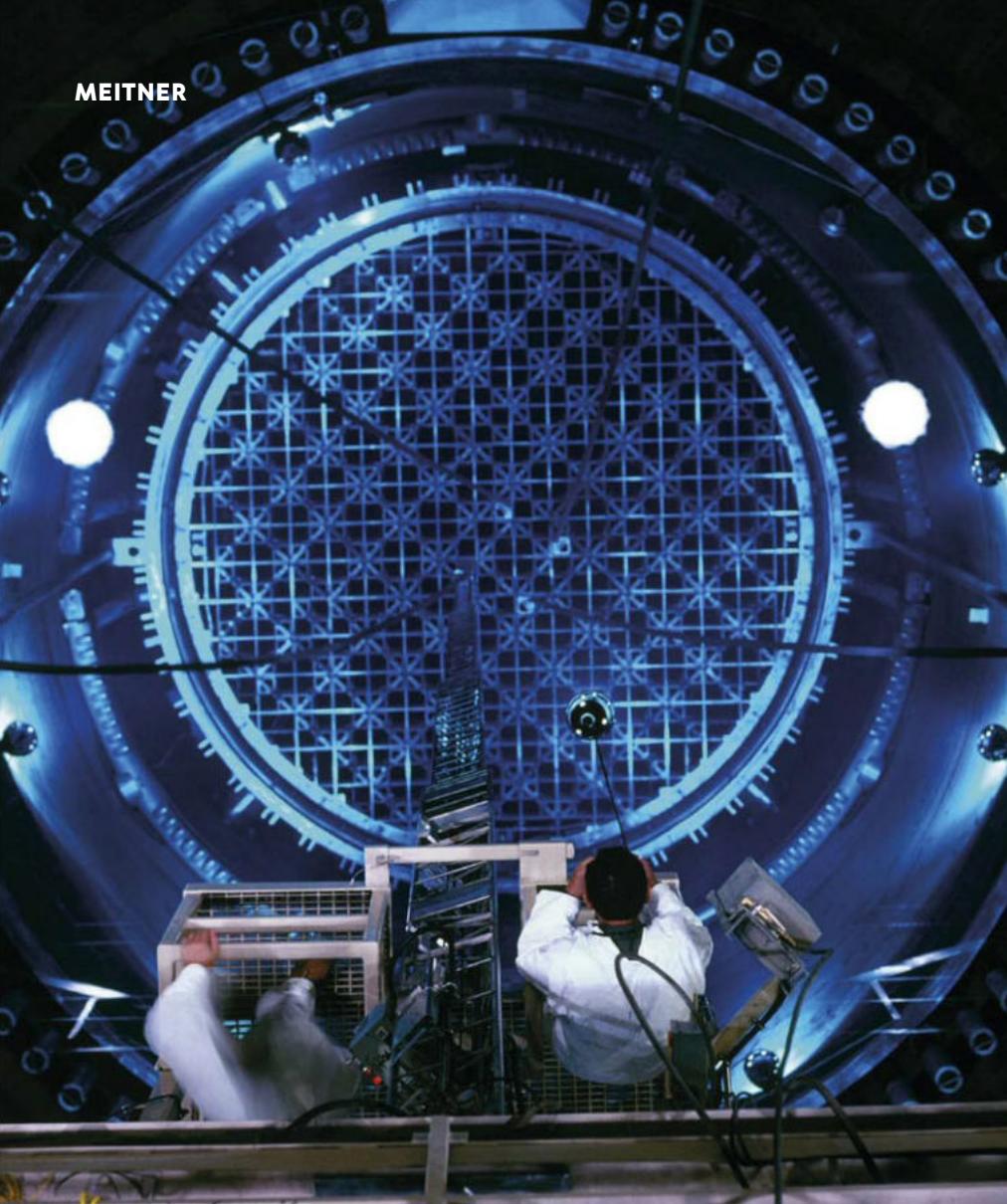
The Manhattan Project at Los Alamos, New Mexico, authorised by US President Franklin Roosevelt, works on the development of the atomic bomb.

6 AUGUST 1945

Little Boy, an atomic bomb that exploits the runaway fission of uranium, annihilates Hiroshima in Japan. A second bomb is dropped on Nagasaki three days later, and Japan surrenders on 15 August.

2017

North Korea conducts a series of missile and nuclear tests, bringing nuclear weapons back into the spotlight.



Nuclear reactor core at a nuclear power station in the US

“We all knew that injustice was taking place, but we didn’t want to see it, we deceived ourselves ... now I must bear responsibility for it”

● informed by Meitner’s insight, led to the advent of nuclear power. Still today, most nuclear power stations rely on uranium fission to produce energy, although there are hopes that one day it will be possible instead to harness nuclear fusion, the process that fuels the Sun, in which very light atomic nuclei release energy as they fuse together. The problems of nuclear fission, especially the production of hazardous nuclear waste, are well known. But in the face of global warming caused partly by the burning of carbon-based fossil fuels like oil and coal, some environmentalists are today turning to nuclear power as a partial solution to the problems we are creating in the Earth’s climate.

THE CONSCIENCE OF GERMAN SCIENCE

Meitner refused to play any part in the Manhattan Project in which the Allies developed the atomic bomb. “I will have nothing to do with a bomb!” she declared.

Being celebrated in America after the war as the “Jewish mother of the bomb”, who somehow kept the secret from Hitler, dismayed her. But much of her energy in the immediate post-war period was spent trying to persuade her former colleagues in Germany to acknowledge and accept their part of responsibility for staying quiet during the horrors that had happened in the Third Reich – over which many of the scientists now wished to draw a veil.

The Allied advance into Germany revealed those horrors to the world, and showed Meitner what she had narrowly escaped. When the troops reached the concentration camps at Dachau and Buchenwald, she wept as she listened to the radio reports. “Someone,” she wrote to Hahn, who was interned in Cambridgeshire in June 1945, “should force a man like Heisenberg and many million others to look at those camps and at the martyred people.”

It took Hahn many years to admit his own culpability. In 1958, he wrote to Meitner on her 80th birthday: “We all knew that injustice was taking place, but we didn’t want to see it, we deceived ourselves... Come the year 1933 I followed a flag that we should have torn down immediately. I did not do so, and now I must bear responsibility for it.”

He thanked Meitner “for trying to make us understand, for guiding us with remarkable tact” towards a recognition of the way the German physicists had worked under, and in many ways for, a monstrous regime. Of the fine words that were later bestowed upon scientists who worked in Nazi Germany, few speak so eloquently as those on Meitner’s tombstone in Hampshire, southern England, where she died in 1968. They pronounce her “a physicist who never lost her humanity”. ●

Philip Ball is a science writer and presenter of *Science Stories* on BBC Radio 4. For more on German physics under the Nazis, read his book *Serving The Reich* (£10.99, Vintage).

DISCOVER MORE



 *Lise Meitner: A Life In Physics* by Ruth Lewin Sime (£30.95, University of California Press).

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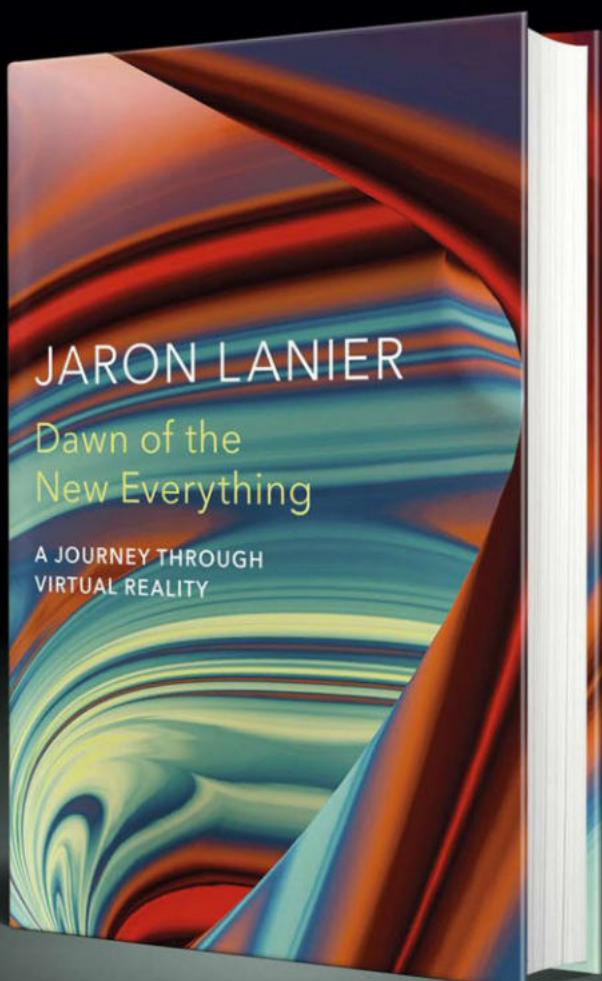
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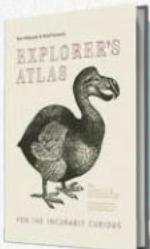
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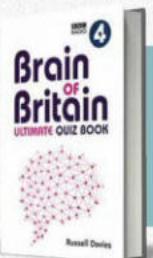
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- Expert interviews with palaeontologists
- Detailed annotated diagrams of all your favourite dinosaurs
- A timeline clearly explaining when different species lived

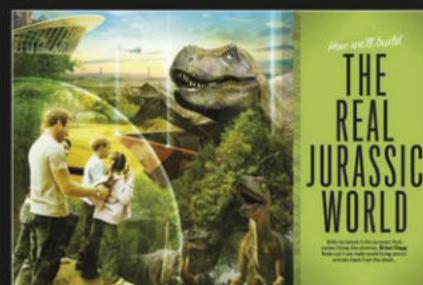
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DISCOVERIES
REVEALED

Q & A



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Astronomer, astrophysicist



ALEX FRANKLIN-CHEUNG
Environment/climate expert



DR PETER J BENTLEY
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Psychologist, sleep expert



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Neuroscientist, science writer



EMMA DAVIES
Health expert, science writer



LUIS VILLAZON
Science/tech writer



DR AARATHI PRASAD
Biologist, geneticist



PROF ROBERT MATTHEWS
Physicist, science writer

YOUR QUESTIONS ANSWERED

DECEMBER 2017

EDITED BY EMMA BAYLEY



Do blind people see in their dreams?

LORELY MASKELL, HIGH WYCOMBE

People who are born blind, or become blind early in life (before around five or seven years of age), do not experience visual imagery when they dream. People who became blind later typically do retain some visual imagery when they dream – but less so than in sighted individuals. A study by Danish researchers found that the longer someone has been blind, the less likely they are to dream visually. And while those who were born blind may not see in their sleep, they are more likely than those with sight to experience auditory, olfactory, gustatory and tactile components to their dreams. **AGr**



Squirrels can even sniff out nuts that are buried under a layer of snow!

How do squirrels find the nuts they buried?

STEPHEN CARTER, PRESTON

It was once thought that they just used their noses to sniff out buried nuts and that the majority were never actually located. But a 1990 study at Princeton University showed that squirrels actually have a good memory and can build a map of the route from one hidden nut to the next. They still use smell to find the caches of other squirrels, but they find a lot more of their own by memory. **lv**

Has anybody had sex in space?

ADRIAN HAYES, IRELAND



No. Spacecraft are too cramped and too public to keep any unauthorised zero-g shenanigans secret, and being caught would almost certainly guarantee that the participants would never go into space again. Officially sanctioned research has begun into two-person sleeping bags that might allow weightless sex, but so far nobody has actually tested them. **lv**

What makes mozzarella cheese so stretchy?

MIRANDA ALLISON, EXETER

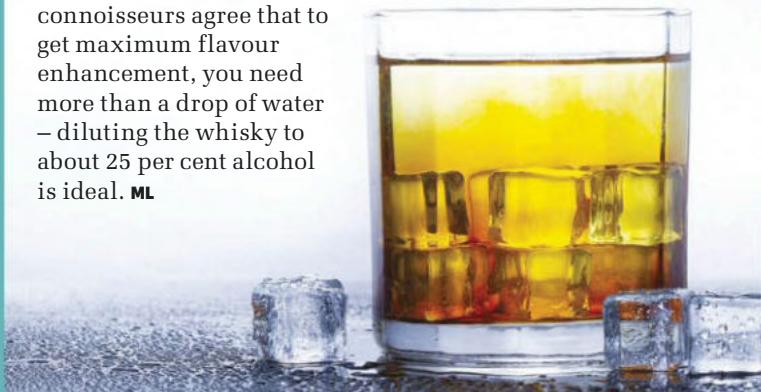
Milk contains proteins consisting of coiled-up chains of molecules. When you make cheese, these proteins are separated out during the curdling of the milk, to make curds. In the manufacture of mozzarella, the curds are then put into hot, salty water. This uncoils the proteins and turns them into long strands, which are then repeatedly compressed and stretched. This forces the strands to line up, creating the famous stringy consistency. **RM**



Why does a drop of water improve the taste of whisky?

GUS MITCHELL, HEMEL HEMPSTEAD

Whisky is predominantly water and ethanol. One end of the ethanol molecule is hydrophilic (water-loving) and the other hydrophobic (water-hating). As a result, the ethanol tends to form a thin layer at the surface of the whisky, with the hydrophobic ends pointing up into the air. Elsewhere in the tipple, it clumps together, forming a so-called micelle, with the hydrophilic ends shielding the other parts of the molecule from the water. Many of the flavours in whisky dissolve better in ethanol, and therefore get locked away in the micelles. When water is added, this disrupts some of the micelles allowing more of the ethanol to migrate to the surface of the drink, along with the volatile flavours. Scientists and whisky connoisseurs agree that to get maximum flavour enhancement, you need more than a drop of water – diluting the whisky to about 25 per cent alcohol is ideal. **ML**



IN NUMBERS

56

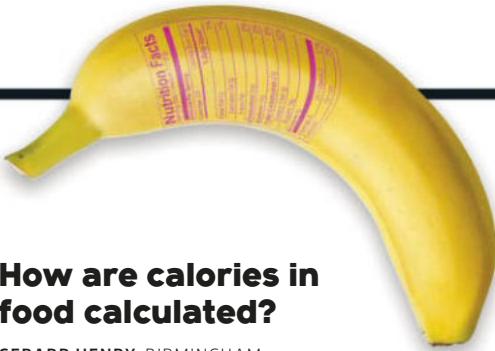
The percentage of green turtle nests lost from Florida's Archie Carr National Wildlife Refuge, after Hurricane Irma.

289

The number of species of Japanese marine life that have washed up in the US on debris from 2011's tsunami.

1,300

The length, in kilometres, of the Deep Underground Neutrino Experiment, which is currently being built.



How are calories in food calculated?

GERARD HENRY, BIRMINGHAM

Calories are a measure of the energy content of food, and as such play a key role in the science of nutrition. During the late 19th Century, scientists began the laborious task of measuring the calorie content of food by burning it in a sealed container and measuring the heat released. While studying the results, a rule of thumb emerged: weight for weight, fat contains nine calories per gram, around twice that in protein or carbohydrates. This led to the so-called Atwater system for calculating the calories in food without lab tests: work out the proportions of fat, protein and carbs it contains, and multiply by the relevant 'Atwater factor' giving the calories contained in each component. But while it's quick and cheap, there's growing concern the Atwater system misses subtleties of how the body uses calories. **RM**

Did *Homo sapiens* and Neanderthals interbreed?

BENJAMIN HATCH, LEEDS



Yes, and more than once! DNA analysis suggests that the earliest encounter between the two species was 100,000 years ago, just as the earliest wave of *Homo sapiens* was migrating out of Africa. They met Neanderthals moving eastwards from Europe to Asia and swapped genes. Later interbreeding periods happened 55,000 and 40,000 years ago, and each time we acquired some Neanderthal genes. Unless you are of sub-Saharan descent, your genome contains 1-4 per cent Neanderthal DNA. **LV**

THE THOUGHT EXPERIMENT

WHAT WOULD HAPPEN IF ALL THE TREES WERE CUT DOWN?

PHOTOS: GETTY X3, ALAMY X2, SHUTTERSTOCK. ILLUSTRATIONS: RAJA LOCKY



1. THE LOGISTICS

There are three trillion trees in the world. The timber industry currently cuts down 15 billion a year, so at current rates it would take at least 200 years to fell them all – probably much longer because a lot of virgin forest is hard to reach. If you gave everyone aged 15 to 65 a chainsaw, they would have to cut down 625 trees each, which might be manageable in a year. But collecting and processing that timber would take much longer and 99 per cent of the trees would just lie on the forest floor, rotting and releasing 35 billion tonnes of CO₂.

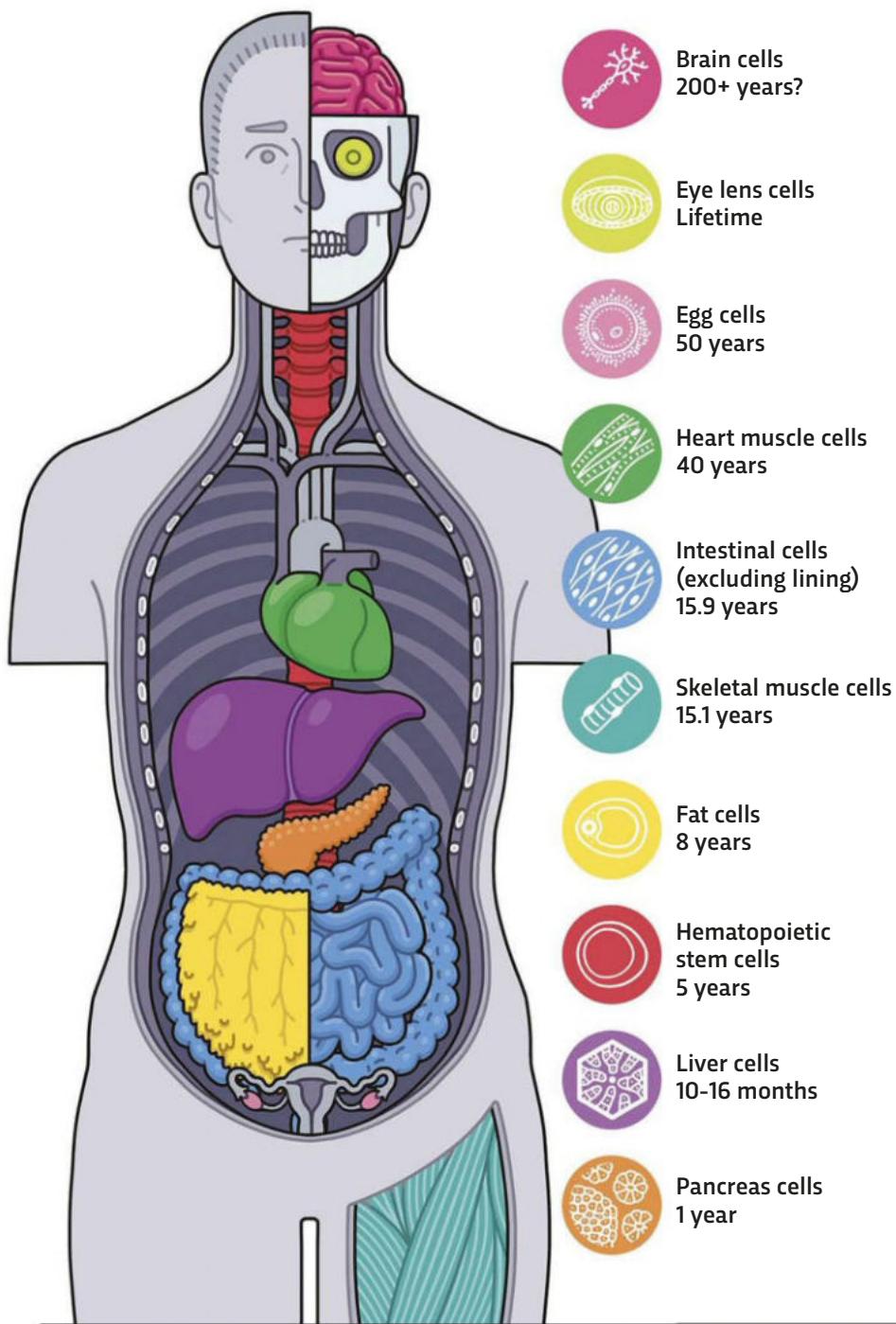


2. ECOSYSTEM COLLAPSE

Eighty per cent of land animals and plants live in forests and without the trees most of them will die. Trees also keep the ground wet and cool, and help to drive the water cycle. A large tree can push 150 tonnes of water into the atmosphere each year, which then falls back on the forest as rain. With no trees, the land will heat up and dry out and the dead wood will inevitably result in enormous wildfires. This will fill the sky with soot that blocks out the Sun, causing failed harvests for several years and leading to worldwide famine.

LONGEST-LIVED CELLS IN THE HUMAN BODY

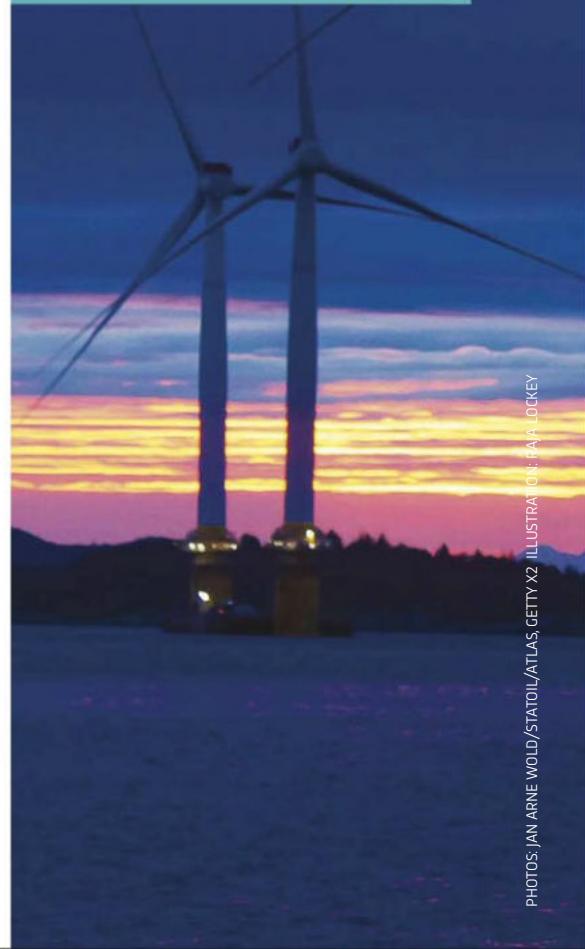
On average, the cells in your body are replaced every 7 to 10 years. But those numbers hide a huge variability in lifespan across the different organs of the body. Neutrophil cells (a type of white blood cell) might only last two days, while the cells in the middle of your eye lenses will last your entire life. And it's even possible that your brain cells might have longer maximum lifespans than you do. In 2013, researchers transplanted neurons from old mice into the brains of longer-lived rats and found that the cells were still healthy after living for two whole mouse lifespans!



How far offshore can wind farms be located?

THERESA WILSON, NEWCASTLE

Sea depth is often the limiting factor when it comes to constructing offshore wind farms. Conventional turbines rest on the seabed and can't be installed in water deeper than about 40 metres. In most regions this means they cannot be built more than 30km from shore. Floating wind turbines could, however, be a game changer. The floating turbines currently being installed at the Hywind wind farm near Peterhead in north-east Scotland can operate in water up to 1km deep. Such technologies could make it possible to build wind farms much further out to sea, where winds are typically stronger. **AFC**





The floating wind turbines being installed at Hywind were built in Norway and towed across the sea to Scottish waters



Why are lips red?

MATTHEW MERTON, BOURNEMOUTH

In the 1960s, zoologist Desmond Morris suggested that a woman's lips evolved to signal sexual receptiveness, by mimicking increased blood flow to the genitalia. Research has shown that men do find the colour red attractive, but a 2012 study at the University of Kent found that men didn't prefer a red vulva, specifically, over a pink one. So lip colour might just be a consequence of the thinner skin there, which improves sensitivity. **lv**

Are fish in a shoal all the same age?

LESLIE WISE, LONDON



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In general, yes. Swirling, spiralling shoals are usually made up of fish of the same species and same size, and hence age. This is partly to confuse predators. Being a similar size, shape and colour makes it difficult for a hunter – a seal, dolphin or bigger fish – to make out and target a single prey fish. Other benefits of forming shoals include swimming efficiency and finding food. Roughly half of all fish species form shoals at some point and one in four species, including sardines, herring and anchovies, live permanently in shoals and get agitated when they're on their own. **ms**

EATING CHOCOLATE GIVES YOU SPOTS



UNCERTAIN

The research evidence is very weak either way. Relatively few studies have looked at the link between chocolate and acne (or milk fat and acne), yet all of them have serious problems with their methodology. Some trials were too short to rule out natural cycles of acne flare-ups, others had too few people, or didn't have proper controls. One study simply involved a questionnaire asking people to recall what they had eaten while in college, years ago, and how bad their acne had been. While there is some evidence that diet can exacerbate acne in people who already suffer from it, there is no clear data to pin down whether it is caused by fat, sugar, hormones in milk, or cocoa. If chocolate does cause spots, the effect seems to be very small. **LV**

Can we remove greenhouse gases from the atmosphere?

WILL MARRITT, HAMPSHIRE

Removing carbon dioxide (CO₂) from the atmosphere is tricky. Some new technologies use chemical filters to extract CO₂ from the air, but come with a hefty price tag. A more promising method relies on plants' natural ability to absorb ambient CO₂ as they grow, transforming it into biomass. Planting trees or crops therefore results in a net

removal of CO₂ from the air. Taking things one step further, this plant matter can be burned inside specially adapted power stations that produce energy while capturing the CO₂ emitted and burying it underground. This technology is, however, still undergoing development. **AFC**



WHAT CONNECTS...

...EXPLODING STREETS AND ZINC?

1.



Explosions

In 1992 a series of 10 explosions in the city of Guadalajara, Mexico, killed more than 250 people. The explosions burst from directly under the downtown streets and left 15,000 people homeless.

2.



Fumes

It was caused by petrol leaking into the sewers, creating explosive fumes. This happened after new water pipes were laid underground, alongside a petrol pipeline that crossed the city.

3.



The water pipes were made of galvanised iron to protect against corrosion but petrol isn't corrosive so the fuel pipeline, owned by the Pemex company, was made from ordinary steel.

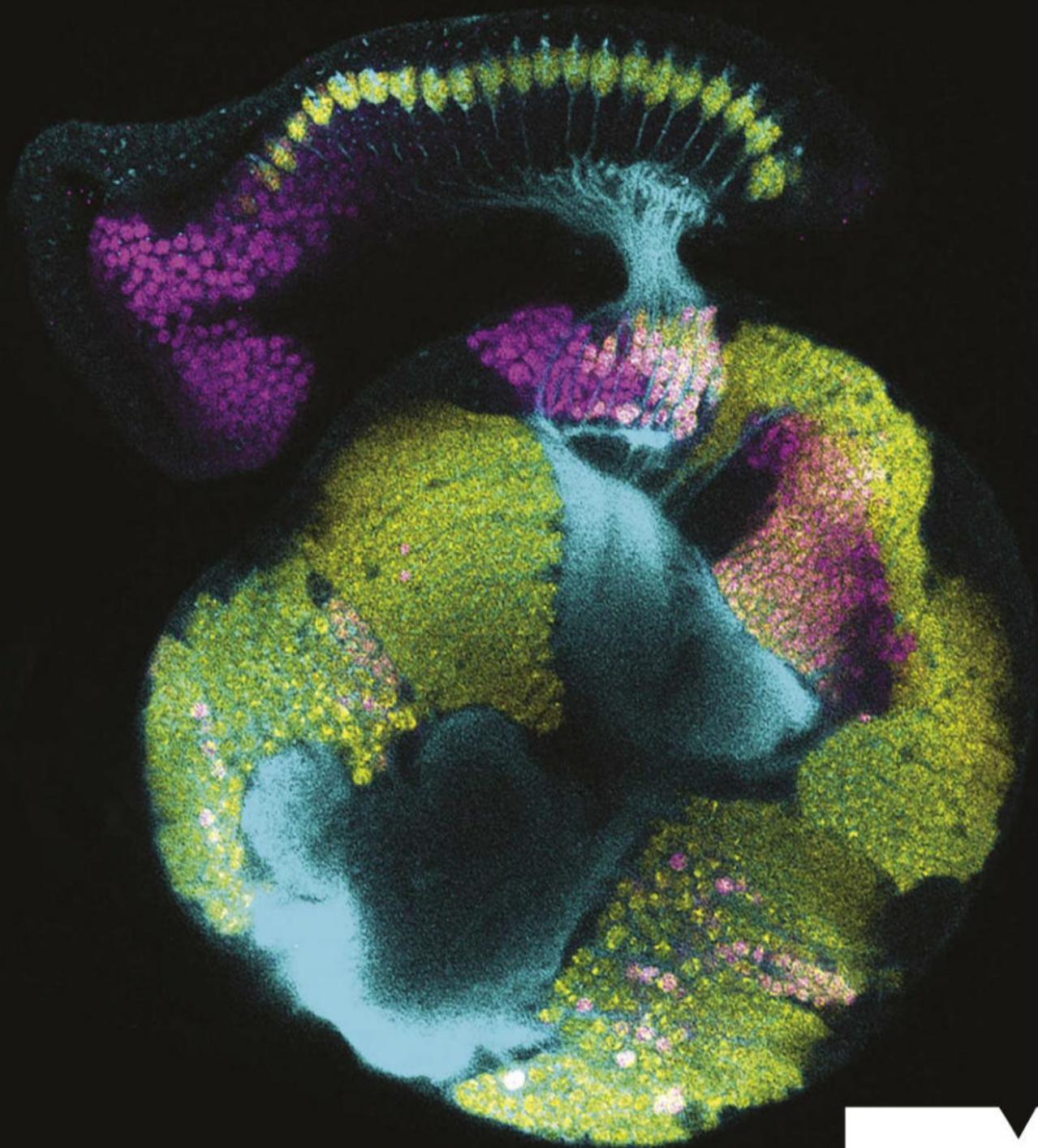
4.



Zinc

The zinc coating on the galvanised pipes caused an electrolytic reaction that turned the damp soil into a battery. The steel pipe acted as the anode and was eroded away, causing the petrol to leak.

WHAT IS THIS?



Visual system of a fruit fly

This microscope image shows the developing visual system in a fruit fly. At the top is the retina, while the large round-shaped structure beneath is the brain's optic lobe. Neurons (nerve cells) are coloured yellow, while their axons (long projections on neurons that conduct electrical impulses) are coloured blue.

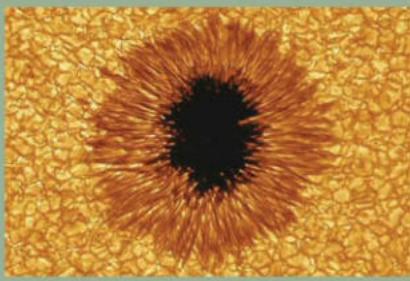
SUNSPOTS

GALILEO
GALILEIJOHANNES
FABRICIUS

Caused by magnetic storms breaking through the Sun's surface, these relatively cool patches appear as black spots that seem to move across the Sun's disc. They are sometimes so large they can be seen with the naked eye through thin cloud or at sunset. As such, their existence has probably been known about since prehistoric times, and Chinese astronomers kept records of them over 2,000 years ago.

However, the true nature of sunspots only became clear with the advent of modern astronomy in the early 17th Century. Belief in the Ancient Greek model of a perfect Universe was still widespread, making the very existence of 'blemishes' on the Sun deeply controversial. In 1611, the Jesuit scholar Christoph Scheiner insisted they were moons in orbit around the otherwise pristine Sun. Galileo was unconvinced, and argued for clouds in the solar atmosphere.

The first person to show the sunspots were features on the Sun itself was a German astronomer named Johannes Fabricius. Using a pinhole camera, he observed clusters of sunspots for months, showing that they vanished over the Sun's western edge, then appeared again two weeks later on the other side. This confirmed they were part of the Sun's rotating surface – and made Fabricius the first solar scientist. RM



...IBUPROFEN TABLETS?

Medical tablets are made from much more than just the active compound. Other ingredients are required to give the tablet volume, colour and to make sure the manufacturing process runs smoothly.

IBUPROFEN

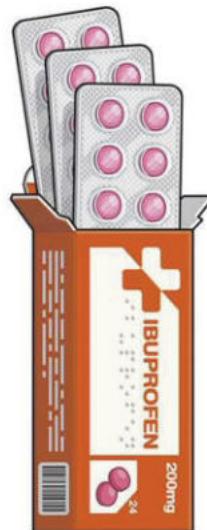
The active ingredient only makes up 200mg of a standard tablet.

LACTOSE

This is used in many tablets, including aspirin and paracetamol, to bulk them out.

SILICON DIOXIDE

This is added during the manufacturing process to help the various powders that make the tablet flow nicely together.



SODIUM LAURYL SULPHATE

A detergent that crops up in many household products, including shampoo and toothpaste. In tablets it is used as a lubricant to stop the various ingredients sticking to manufacturing equipment.

TITANIUM DIOXIDE

This turns up in a lot of products, from tablets to sunscreen to paint. It is used as a white pigment.



Do all galaxies rotate in the same direction?

BRIAN SHIMELL, BANSTEAD

If all galaxies formed from the same cloud of spinning material, we might expect their spin directions to be the same. This is similar to the planets of the Solar System, which all spin in the same direction as the proto-planetary cloud from which they formed (except for Venus and Uranus which were probably made to spin in the opposite direction by large impacts). But, although galaxies do not form from the same cloud of material, they are not randomly distributed in space; they form along 'filaments' with 'voids' in between. This means that proto-galaxies actually are gravitationally

linked in small areas of the Universe and this is probably a result of the distribution of dark matter throughout the Cosmos. The matter in these filaments tends to move in a corkscrew motion towards the area of highest density. The result of this is that there can be a preferential direction of spin for galaxies forming in the same filament, although it also depends on the galaxy's mass. Hence, if we look out into the Universe, there can be areas that appear to have a preferential direction for galaxy rotation, but averaged over the whole Universe, their spin direction is actually random. AG

Why does spicy food make my nose run?

SMERA AHUJA, WINCHESTER



Spicy compounds are produced by plants to deter animals from eating them. They have evolved to be as irritating as possible to the mucous membranes of mammals. In fact, the capsaicin in chilli doesn't actually cause tissue damage, but it triggers the nerve receptors that normally detect heat, and your nose is fooled into producing extra mucus to protect your sinuses. **lv**



Why do I weigh less in the morning?

FINBAR McDONNELL, BERKHAMSTED

Because you are alive! The chemical reactions that sustain you all require energy, and even though you aren't eating in your sleep, these metabolic processes are still converting glucose molecules into carbon dioxide (CO_2) and water. The air you breathe out contains 4 per cent CO_2 and is saturated with water vapour. In a typical eight-hour sleep you will exhale 2,100 litres of air, containing 27g of water and 84 litres of CO_2 . The carbon in the CO_2 weighs 42g. While 69g in a night doesn't sound like much, you also lose weight from your sweat, the saliva you dribble onto the pillow, and from the skin flakes you shed into the sheets. This is why you need to change the bedding every now and again. **lv**

QUESTION OF THE MONTH

Will rising sea levels mean mountains have to be recalibrated?

DAMIEN BUTLER, WORTHING

It's not that simple. Although average height of the sea is rising, this does not affect Mean Sea Level (MSL). MSL is a reference level that refers to historical measurements. In the UK, MSL is defined by data that was collected from tide gauges in Newlyn in Cornwall between 1915 and 1921. But mountain elevation isn't measured relative to sea level anyway. Now, map makers use a geoid, which is a mathematical representation of the Earth, to define the reference height. The geoid is the hypothetical shape that all the oceans of the world would take if they were only affected by gravity and the Earth's rotation. In other words, it excludes the effects of weather and tide. The geoid is determined by measuring the gravity fluctuations over the Earth's surface, due to the varying thickness of the crust and densities of magma below. The reference geoid does get adjusted from time to time, and in 2016, Calf Top in the Yorkshire Dales was promoted from a hill to a mountain because changes to the geoid meant it was now 2cm taller than previously recorded. But this was because of more accurate modelling, not changing sea levels. **lv**

WINNER!

Damien Butler wins a bioluminescent Dino Pet from Biopop (£60, biopop.com). This dinosaur-shaped aquarium is filled with microscopic sea life called dinoflagellates that glow a fabulous blue colour if you play with them at night. All they require is indirect light and special nutrients (included).



NEXT ISSUE:

How can I live to be 100?

Is vaping safe?

Why do ants walk in a line?

Email your questions to questions@sciencefocus.com or submit online at sciencefocus.com/qanda

OUT THERE

WHAT WE CAN'T WAIT TO DO THIS MONTH

DECEMBER 2017

EDITED BY JAMES LLOYD

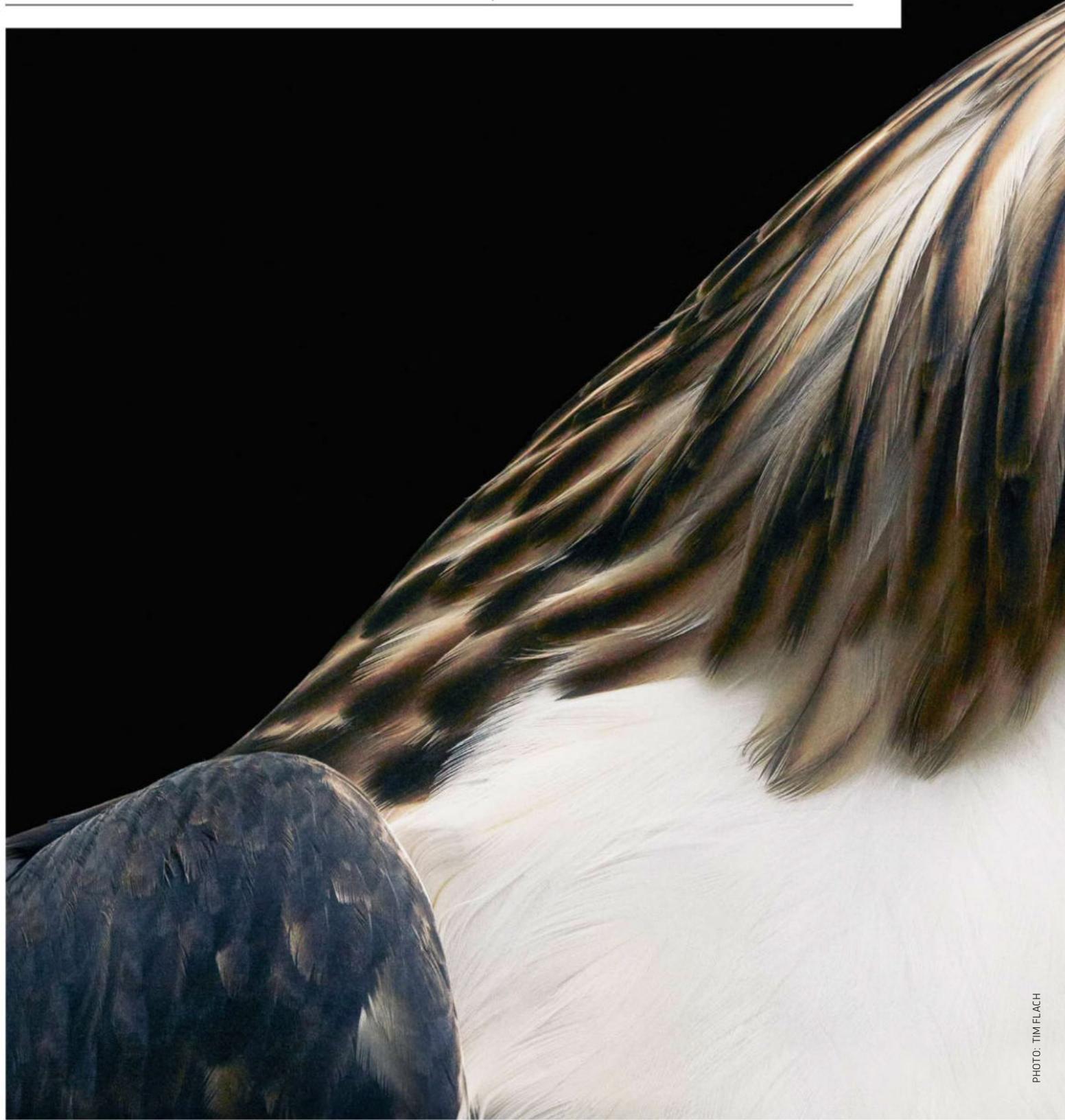


PHOTO: TIM FLACH



01

ENDANGERED

BY TIM FLACH, WITH TEXT BY JONATHAN BAILLIE
OUT NOW (£50, ABRAMS).

MEET THE PHILIPPINE EAGLE

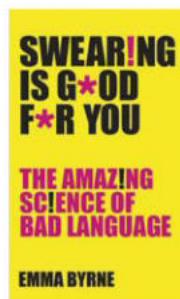
With a wingspan of two metres, the Philippine eagle is one of the world's largest birds of prey, but also one of the most endangered. There are thought to be less than 1,000 remaining in the wild, its existence threatened by poaching, pollution and deforestation.

This charismatic bird features in *Endangered*, the result of an epic project by Tim Flach to photograph some of the most threatened species on Earth. Combining stylised, deeply emotional portraits of the animals with images taken in their natural habitat, the book aims directly for the heart, highlighting their vulnerability and all-too-delicate existence. There are the iconic animals such as lions, tigers, elephants and pandas, but also lesser known species such as the olm – a blind, aquatic salamander that wouldn't look out of place in a Guillermo del Toro film – and the adorable pangolin, described as “an artichoke with eyes”.

02

SWEAR LIKE A CHAMP

SWEARING IS GOOD FOR YOU
BY EMMA BYRNE
OUT 19 NOVEMBER
 (£12.99, PROFILE BOOKS).



Swearing is found in every language, and even chimps do it. But why do we swear, and is it a good thing? We chat to EMMA BYRNE, author of a new book on the subject.

Why do some words have such a power to shock?

It's all to do with our taboos as a society. Swear words tend to be based around the things that we think of as sacred, private or slightly shameful: religion, sex, bodily functions, questionable parentage. But what constitutes bad language changes from place to place and from time to time.

In English, there are nursery rhymes containing racial slurs that we wouldn't dream of teaching our kids today; in French-speaking Canada, the word 'tabarnak' (tabernacle) is an incredibly strong swear word related to religion, whereas in France that word isn't used at all. So it's not about the sound of the word, but the meaning and the context.

In what ways is swearing good for us?

Most famously, swearing can relieve pain. Earlier this year, a study at Keele University asked undergraduates to plunge their hands into ice-cold water and then repeat either a swear word or a neutral word. The students who repeated the swear words were able to keep their hands in the water for much longer than their non-swearing counterparts.

Follow-up work has shown that swearing increases our heart rate and galvanic skin response – that feeling of sweaty palms we get when we're stressed. So swearing seems to be doing something physiological to the body, preparing it for a fight-or-flight response and allowing it to be more resilient to pain.

Does swearing have any other benefits that we know of?

Swearing is a strong signal of emotional intent, so it's a useful social tool. Research with

chimpanzees has shown that they invent swearing as soon as they have taboos and a means of communication available.

Hang on... chimps swear?

When chimps are taught to use sign language, they're also typically potty trained. They often internalise this potty training as a taboo around everything to do with going to the toilet – it becomes something shameful to them. And remarkably, the chimps sometimes then use the sign for doing a poo – 'dirty' – to express themselves when they're angry, frustrated or dismayed. It allows them to express strong emotions without doing anything physically harmful.

This might be why swearing originally came about in humans, too. Imagine a small tribe of proto-humans first learning to hunt bison together. If one of your number does a really bad job, you might say, "Hey Zog, you really f—ed up that hunting manoeuvre today". Being able to use those swear words, rather than just hitting Zog over the head with a rock, means that your tribe will recover from the disappointment much more easily. Zog realises he's got to buck his ideas up, but nobody gets injured in a fight.

Are there any discernible gender differences in swearing?

It was believed for a long time that women didn't swear as much as men, until women scientists started carrying out some of these studies and found the opposite. It turns out that women are just a lot less comfortable swearing in front of men, and the same for men in front of women. There are actually very few differences between male and female swearing. Women tend to use slightly milder swear words,

and when they swear in front of men it's usually to demonstrate that they are competent, strong, combative. On the other hand, when guys swear with other guys it's usually about sympathising with emotions such as frustration and anger. But more jocular swearing is pretty much even between the genders.

Is swearing found in every language?

Yes, but it's not always based around the same taboos. In Dutch, there are swear words based around illness, such as 'typhoid' and 'cancer'. This goes back to the idea of 'word magic' – that just naming something can be enough to make it happen. In German, calling someone a 'pig' or a 'dog' is enough to get you fined, while in the Middle East, there are moustache-based swear words, because insulting someone's facial hair can be construed as a comment on their masculinity.

Should we be trying to swear more?

The last thing I would want is for the swear words we're currently using to become so commonplace that we have to start reaching for more offensive words. It's then that we start getting into the slurs on people's race or sexuality. The great thing about the 'f' word and the 's' word is that everybody is the product of intercourse and everybody goes to the toilet – they're universal to the human experience.

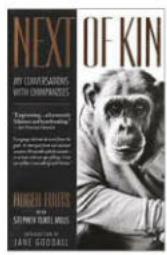
Swearing is like paracetamol or jogging – it's good for you until it starts causing more harm than good. Use swear words in conversation like you'd use seasoning in cooking. You wouldn't want an entire meal of them, but occasionally they just add a little something to the dish.



Swearing may have evolved as a way to express anger and frustration without resorting to violence

AUTHOR'S BOOKSHELF

Three books that inspired Emma Byrne while writing *Swearing Is Good For You*



NEXT OF KIN

BY ROGER FOUTS

(\$15.99, WILLIAM MORROW PAPERBACKS).

I drew heavily from this book for the primates chapter of Swearing Is Good For You but there's so much that I really regret having to leave out. Chimpanzee cognition is so similar to our own that it's astounding.



SWEARING IN ENGLISH

BY TONY MCENERY

(£32.99, ROUTLEDGE).

This book was an indispensable introduction to corpus linguistics – the study of huge collections of spoken and written language. It started me down the path of wondering how society shapes our swearing, and why some words are 'powerful' and others are 'pure'.



BONK

BY MARY ROACH

(£9.99, CANONGATE).

It's hard to select just one of Mary Roach's books. Her passion and doggedness really inspire me, whether she's writing about what happens to our bodies when we die, or persuading her husband to have sex with her in an MRI scanner for science.

03

VENOM: KILLER AND CURENATURAL HISTORY MUSEUM, LONDON
10 NOVEMBER 2017 – 13 MAY 2018.

AVOID BEING STUNG

Venom is one of nature's most extraordinary inventions. Used by animals to capture prey or fend off rivals, it's also finding an unlikely use in lifesaving drugs. A new exhibition at the Natural History Museum showcases both the life-destroying and life-giving properties of venom. We'll meet some of the world's most venomous creatures, including the lethal stonefish and the gaboon viper with its 5cm-long fangs, and we'll hear about the latest uses of venom in medicine. There'll even be chance to get up close to a live venomous animal.

To whet our appetite, we asked Dr Ronald Jenner, venom expert at the Natural History Museum and the exhibition's lead scientist, to surprise us with five lesser-known facts about these toxic substances.

1. IT'S NOT ALL ABOUT SNAKES AND SPIDERS

"Most people associate venom with arachnids and snakes, but among the 200,000 species of venomous animal are fish, amphibians, lizards, and a handful of mammals, including the platypus and some species of shrew. No animal has evolved its venom to target humans specifically, but we have a similar physiology to the animals it's targeted at, so the venom often has an effect on us, too."

2. YOU DON'T WANT TO CROSS A PLATYPUS

"The male platypus has venomous spurs on its hind legs that it uses to stab its rivals during mating season. If you get stung by a platypus, you'll be sorry for weeks. The only way to treat it is by deadening the nerves affected by the venom – even morphine doesn't do anything. It's so painful that you lose the ability to think."

3. THE BOX JELLYFISH CAN KILL A HUMAN IN THREE MINUTES

"The most venomous animal to humans is the box jellyfish, whose venom destroys skin, attacks blood cells, damages nerves and can give you a heart attack within minutes. Equally horrific is the venom of the coastal taipan snake in Australia and New Guinea, which damages the blood's ability to clot, causing major bleeding and then paralysis and death – all within an hour."

4. VENOM IS SAVING LIVES

"Drugs developed from venom have been used to treat diabetes, high blood pressure and chronic pain. One of the most exciting areas of research is a neurotoxin from a sea anemone in the Caribbean. It's successfully been used to treat the skin condition psoriasis, and the hope is that it might one day be used to treat other autoimmune diseases such as multiple sclerosis."

5. SCORPION SEDUCTION HAS A STING IN ITS TAIL

"One of the more bizarre uses of venom occurs in the emperor scorpion. They typically use their venomous stinger for attacking prey and defence against predators, but when mating, the male injects his stinger into the female to sedate her. We're not sure exactly why, but it could be to make her less aggressive and easier to manoeuvre over the sperm packet he's deposited on the ground."

If you ever see one of these in the water, steer well clear...



04

LEONID METEOR SHOWER
16-18 NOVEMBER.

SPOT A SHOOTING STAR

The nights are drawing in, but that means there's more chance to explore the night sky. This month's top sight is the annual Leonid meteor shower, created as the Earth passes through a stream of dust particles left in the wake of the comet Tempel-Tuttle. As these pea-sized particles hit our atmosphere, they heat up and ignite, creating the 'shooting stars' that we see streaking across the sky. Here are our top tips for spotting the Leonids:

- **Check your diary.** The meteor shower is due to peak at 16:30 GMT on 17 November, so the nights of 16/17 and 17/18 November are the best time to spot them. The shower follows a 33-year cycle and we're not currently in the most active phase, but we can still hope to see around 10 meteors per hour.
- **Look eastwards.** The Leonids appear to come from the constellation of Leo (hence their name) in the northeast, but as long as you look in an eastwards direction you should be able to see them. The good news this year is that the Moon is in its new phase, which means that the meteor shower won't be drowned out by moonlight.
- **Dig out your sunlounger.** You don't need any special equipment to see the meteors. Just find a dark location away from any lights, and get relaxed in a reclining chair to avoid straining your neck. It will take at least 20 minutes for your eyes to become accustomed to the dark. Be prepared to spend a couple of hours outside, but take a break every 30 minutes, and don't forget to wrap up warm!

For a full monthly guide to the night sky, check out BBC Sky at Night magazine. The December issue is on sale from 16 November.



PHOTOS: GETTY, ALAMY

5 MORE DATES FOR YOUR DIARIES

1 OPEN DAILY

AEROSPACE BRISTOL

Located at Filton Airfield just outside Bristol, the star attraction at this new aviation museum is Concorde Alpha Foxtrot – the last of the iconic supersonic passenger jets to fly.

2 UNTIL 8 APRIL 2018

AYURVEDIC MAN: ENCOUNTERS WITH INDIAN MEDICINE
WELLCOME COLLECTION, LONDON

This free exhibition opens on 16 November and consists of manuscripts, paintings, erotic manuals and surgical tools relating to Ayurveda and Indian medicine.

3 17 NOVEMBER

STAR WARS BATTLEFRONT II
PC/PS4/XBOX ONE

This sequel to 2015's rebooted *Star Wars Battlefront* will feature the usual epic multiplayer battles plus a single-player story mode, allowing you to explore the galaxy through the eyes of Commander Iden Versio.

4 18/19 NOVEMBER

THE FIRST WOMAN ON THE MOON
BBC WORLD SERVICE

In the early 1960s, Wally Funk was one of 13 female pilots who trained for space. She never got her chance to fly, but in this documentary she meets those who are hoping to return to the Moon. Who will be the first woman to set foot on the lunar surface?

5 UNTIL 18 MARCH 2018

ANNA DUMITRIU: BIOART AND BACTERIA
MUSEUM OF THE HISTORY OF SCIENCE, OXFORD

This free exhibition runs Tues-Sun and explores our relationship with the microbial world, antibiotics and technology. Artist Anna Dumitriu combines traditional techniques and contemporary science to create her thought-provoking, sometimes unsettling works.

FIND OUT MORE

For more of this month's best events, shows and books, head to bit.ly/BBCFocusBrainFood



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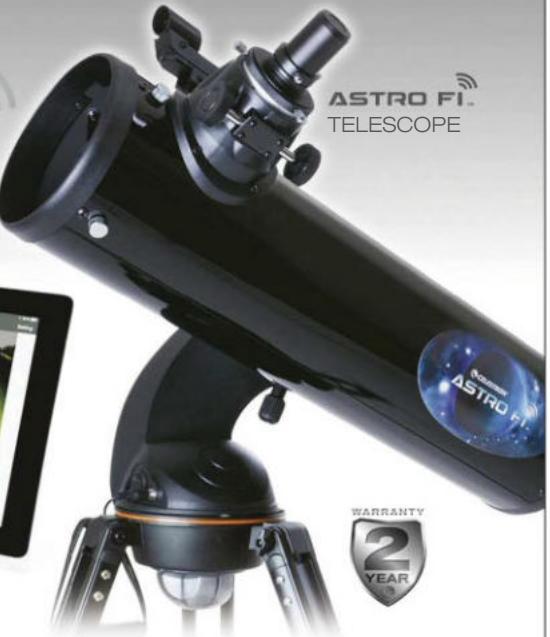
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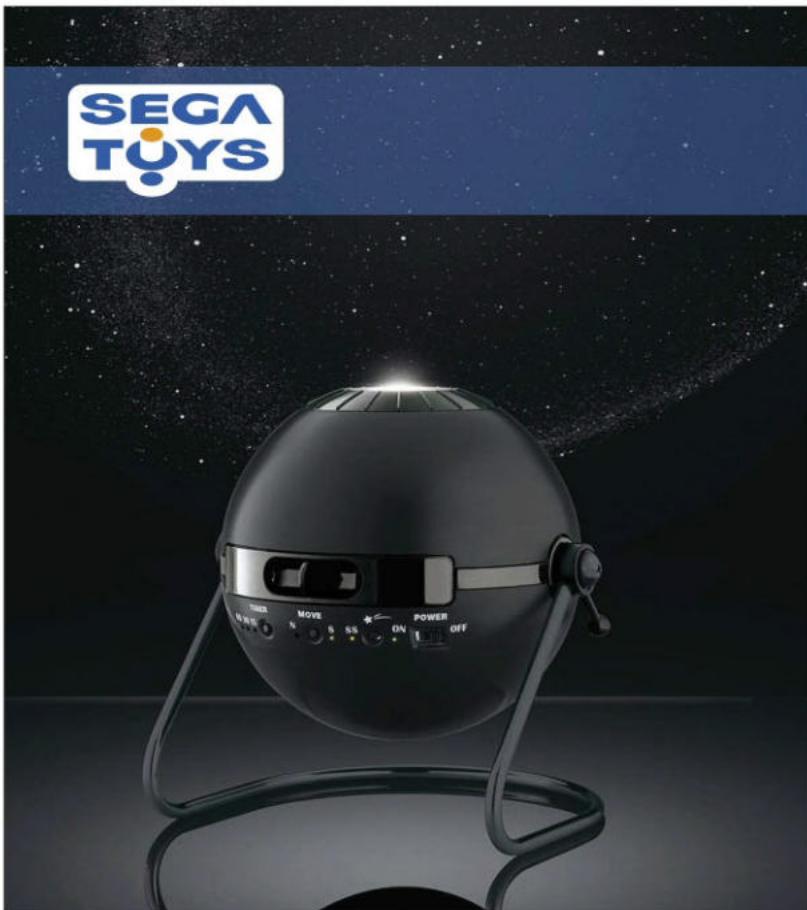
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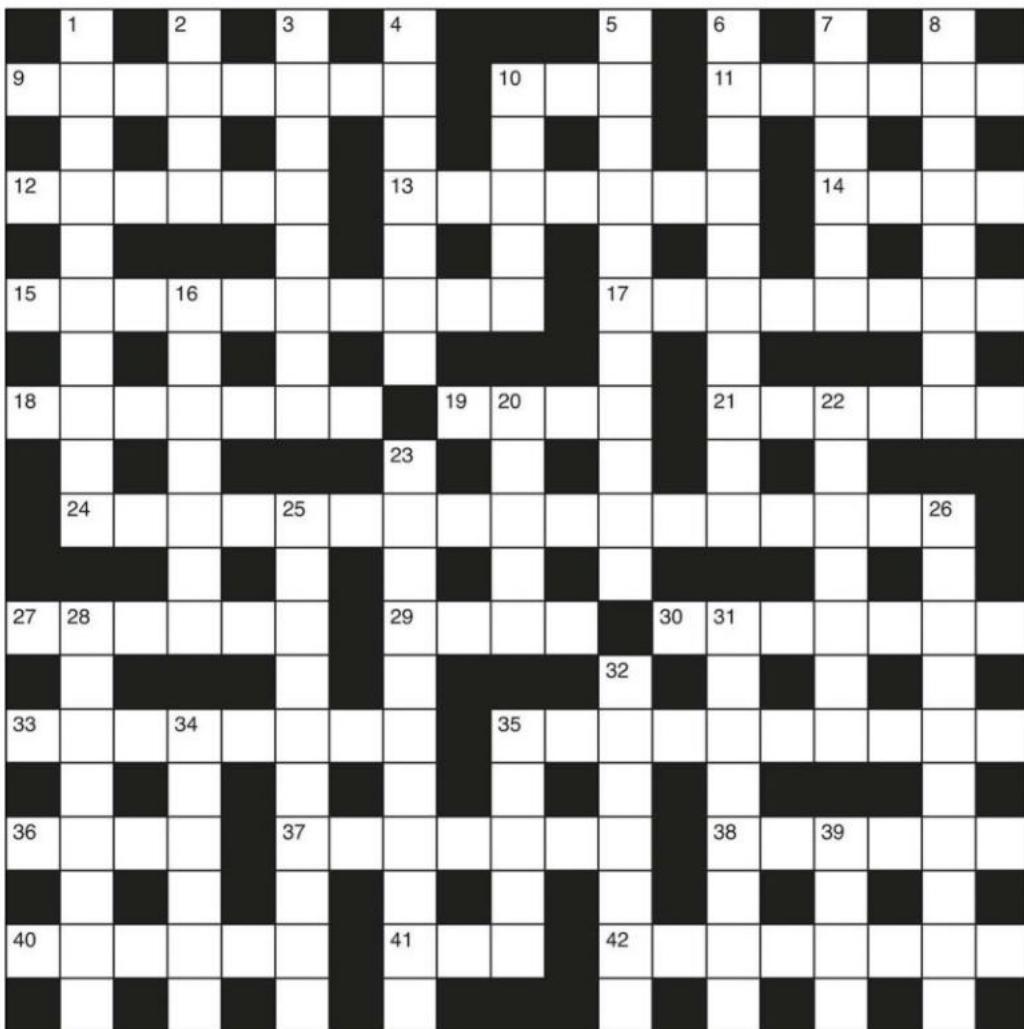
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GIVE YOUR BRAIN A WORKOUT



ACROSS

9 Hat piece has transformed and covered in spines (8)
 10 Pressure is turned on foreign character (3)
 11 Flammable mixture and sodium found on tree (6)
 12 Fastening in series (6)
 13 Care about taking that fellow a mythical hybrid (7)
 14 Lug around last of paste and adhesive (4)
 15 Profound sailor ruins bream recipe (10)
 17 Laugh at spies having to finish estate (8)
 18 Splitting if new ship takes one on (7)
 19 A rug woven from wild ox (4)
 21 Island river has politician corrupted (6)
 24 Dancer's instalment about philosophical movement (17)
 27 Joke about leg to some geese (6)

29 Initially drive king around America in the evening (4)
 30 Parasites have a race in grid (7)
 33 Anaesthetic rule paid off (8)
 35 Distorted memory of soldier in same deployment (10)
 36 Pig gets chilblain, ultimately, in cold weather (4)
 37 Alive, somehow getting round large parts of the lung (7)
 38 Number of points in tiny composition (6)
 40 Animal feed, in gale, is troublesome (6)
 41 You forgot about something seen in the sky (3)
 42 Mark seat out by chance (8)

DOWN

1 Green traveller finds cruise too random, with time (10)
 2 Fruit for a bird (4)
 3 Rook flying round a nag, disturbing marsupial (8)
 4 Proper to have singular ancestry (7)
 5 Use of computer system sold by touts abroad (4-7)
 6 Worker, very cold, reaches a continent (10)
 7 Primate has to go back and point to the summit (6)
 8 Struggle to fish (8)
 10 Previous clergyman (5)
 16 Gullible person has ants mistaken for horse (7)
 20 Danes out of range (5)
 22 Reportedly remove unwanted stuff from potion (7)
 23 Strangely immune, delve into an element (11)
 25 Shares out drink to seabird (10)
 26 Coat for Art Nouveau architect (10)
 28 Postscript that's pointless to humans (8)
 31 Omit name change to fossil (8)
 32 Trains a new craftsman (7)
 34 Fold of skin gets friend married the wrong way (6)
 35 Hop around on broken plug (5)
 39 Dull expert sees nude's front and turns red (4)

ANSWERS

For the answers, visit
bit.ly/BBCFocusCW
 Please be aware the website address is case-sensitive.

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"It all started when I got stabbed. It made me think about the knife and what it was made from"

This month, **Helen Pilcher** talks to **Mark Miodownik**, professor of materials and society at UCL, and founder of the Institute of Making

What do you do?

I have been described as a professor of the mundane. I like that. Materials science is about noticing how the world works, then trying to make it work differently. Everything is made of something and that stuff is what I study.

How did you get interested in all this?

It all started when I got stabbed. I was 15 and this guy at the tube station said he would stab me if I didn't give him money. I didn't believe him, so when the train arrived I pushed past him and got on. But he did stab me. It made me think about the knife and what it was made from. It was just this thin wafer, but it almost killed me.

What cool materials have you made?

We're trying to create self-healing materials for roads so they can fix themselves. We've also made spoons that have different flavours, so when you eat a meal with them, they change what you taste. It means you can make things taste sweeter without adding any extra calories. Sometimes taste malfunction is an early sign of disease so we're imagining a spoon that would somehow flag up when you're getting ill.

What's your favourite material?

I regard materials a bit like you should regard your children. The worst thing you could possibly say is that you have a favourite. That would be wrong because you love them all the same but for different reasons.

If stone, bronze and iron are the past, what's the future?

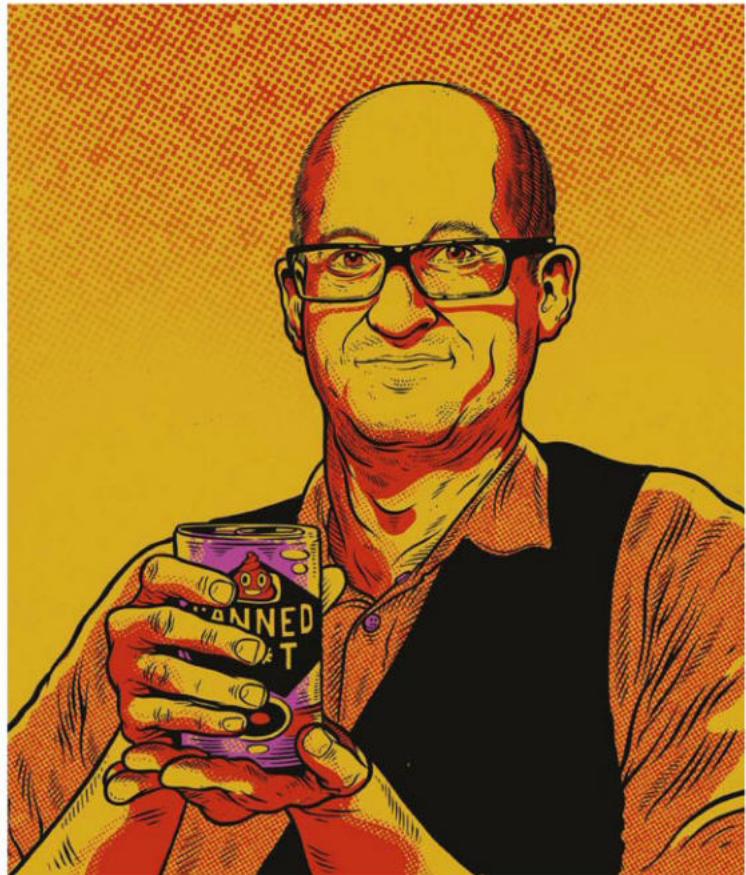
We name these 'Ages' after materials because at the time, they change everything. I think we're moving out of the Silicon Age into the Age of Animate Materials – materials that blur the line between living and non-living.

What bit of tech would you like to see most?

We've got this idea for a fabric exoskeleton you wear under your clothes that tenses around your joints to help you move. We've made a material that can sense movement. The next step is to make it mechanically respond. I've got dodgy knees so I think it would be great. I'd like to be skiing until I'm 100 wearing one of these suits.

Any epic fails?

The Tate Modern had a 1950s piece of artwork that was



canned s**t, but no one knew whether or not the can actually had s**t in it. They asked me to find out using modern methods, but without opening it. It seemed like a pretty easy thing to do. After all we've put people on the Moon and we have MRI scanners. But no. I tried but I couldn't do it.

How do people describe you?

A combination of annoying and enthusiastic in equal measure. I think that's fair. I annoy myself.

Prof Mark Miodownik is a materials scientist. He was recently awarded the Michael Faraday Prize for excellence in communicating science.

[DISCOVER MORE](#)



To listen to an episode of *The Life Scientific* with Mark Miodownik, visit bbc.in/2fX1ayf

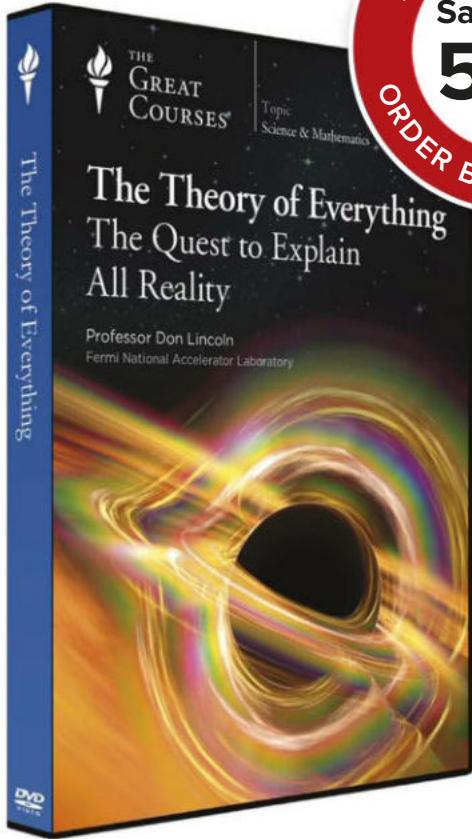
NEXT ISSUE: RAJ LADA

If you could change one thing about yourself, what would it be?

I wish I wasn't bald. I really envy people with hair. It doesn't matter how much reassurance I get, I just look in the mirror and at photos and obsess about it.

How about you make some kind of animated hair material?

You're right. That's a good idea. I'm going to think about that.



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